



NIF Laser Capabilities

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NIF Users Group
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**C. Haynam, JM Di Nicola, P. Wegner,
M. Bowers, D. Browning, S. Burkhart, S. Cohen, A. Deland, P. Di Nicola, S. Dixit, G. Erbert,
M. Henesian, M. Hermann, R. House, K. Jancaitis, K. LaFortune, R. Lowe-Webb, K. McCandless,
V. Miller Kamm, M. Nostrand, C. Orth, B. Raymond, R. Sacks, M. Shaw,
B. Van Wonterghem, P. Whitman, C. Widmayer, K. Wilhelmsen, L. Wong.**

**7000 East Avenue, Livermore, CA 94550, USA
haynam1@llnl.gov**

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1.6 MJ, 435TW
September 15, 2011



Cluster 4

Cluster 3

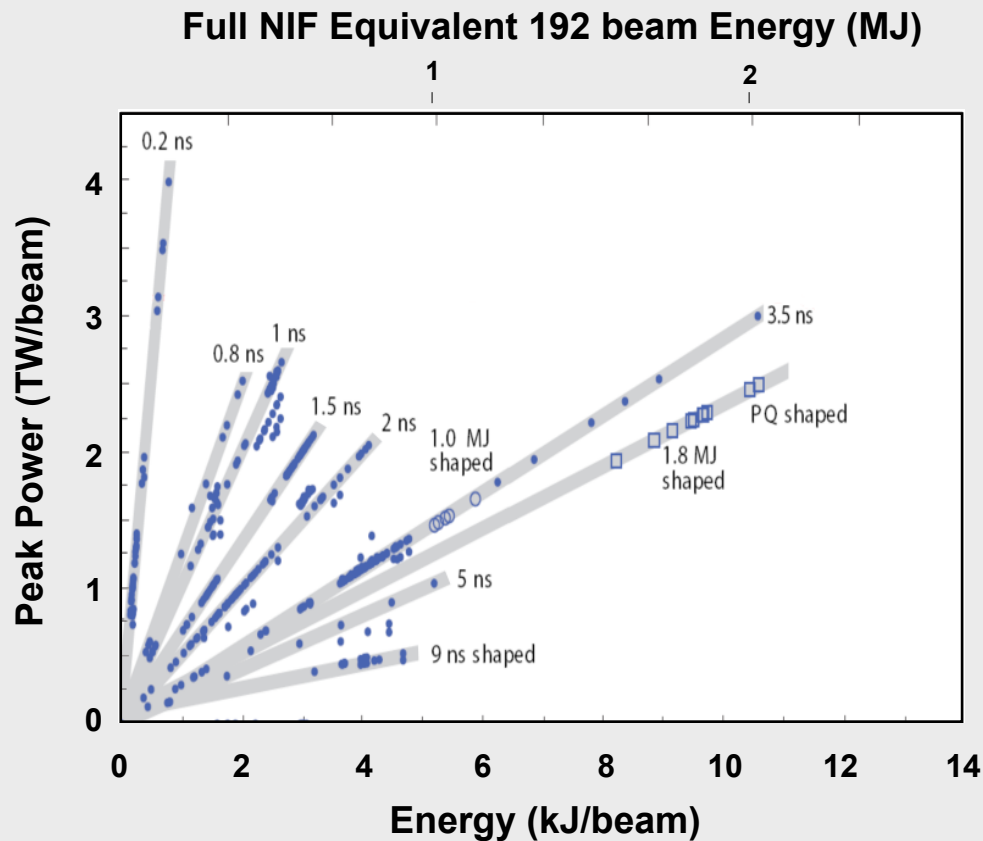


Cluster 2

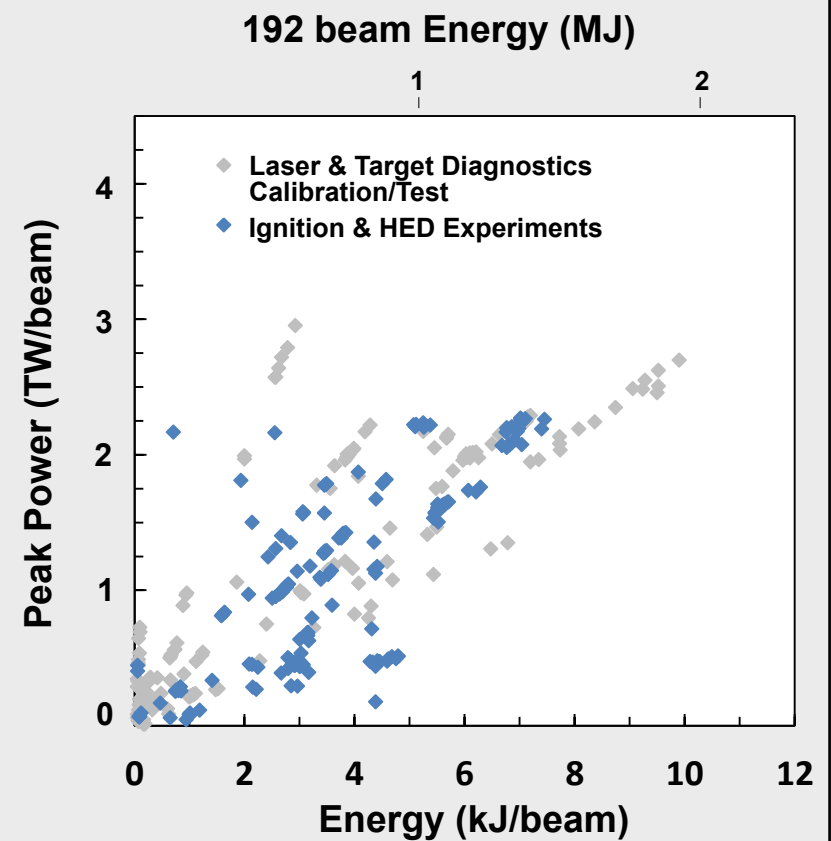
Cluster 1

The NIF laser system is flexible and has supported a wide variety of shot campaigns

NEL and PDS 3ω Experiments Mar 2003 to Sep 2007

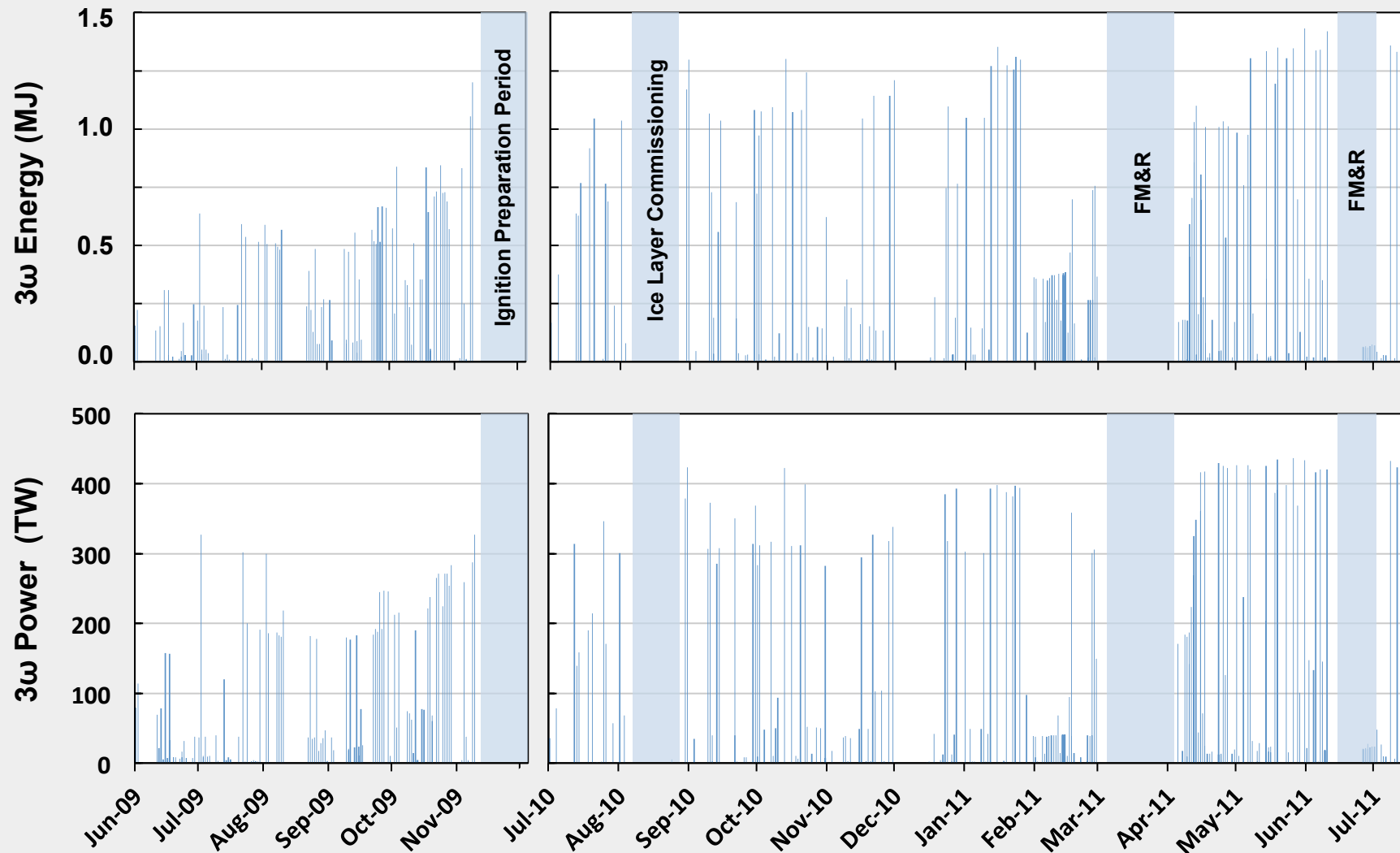


NIF 3ω Experiments June 2009 to Aug 2011



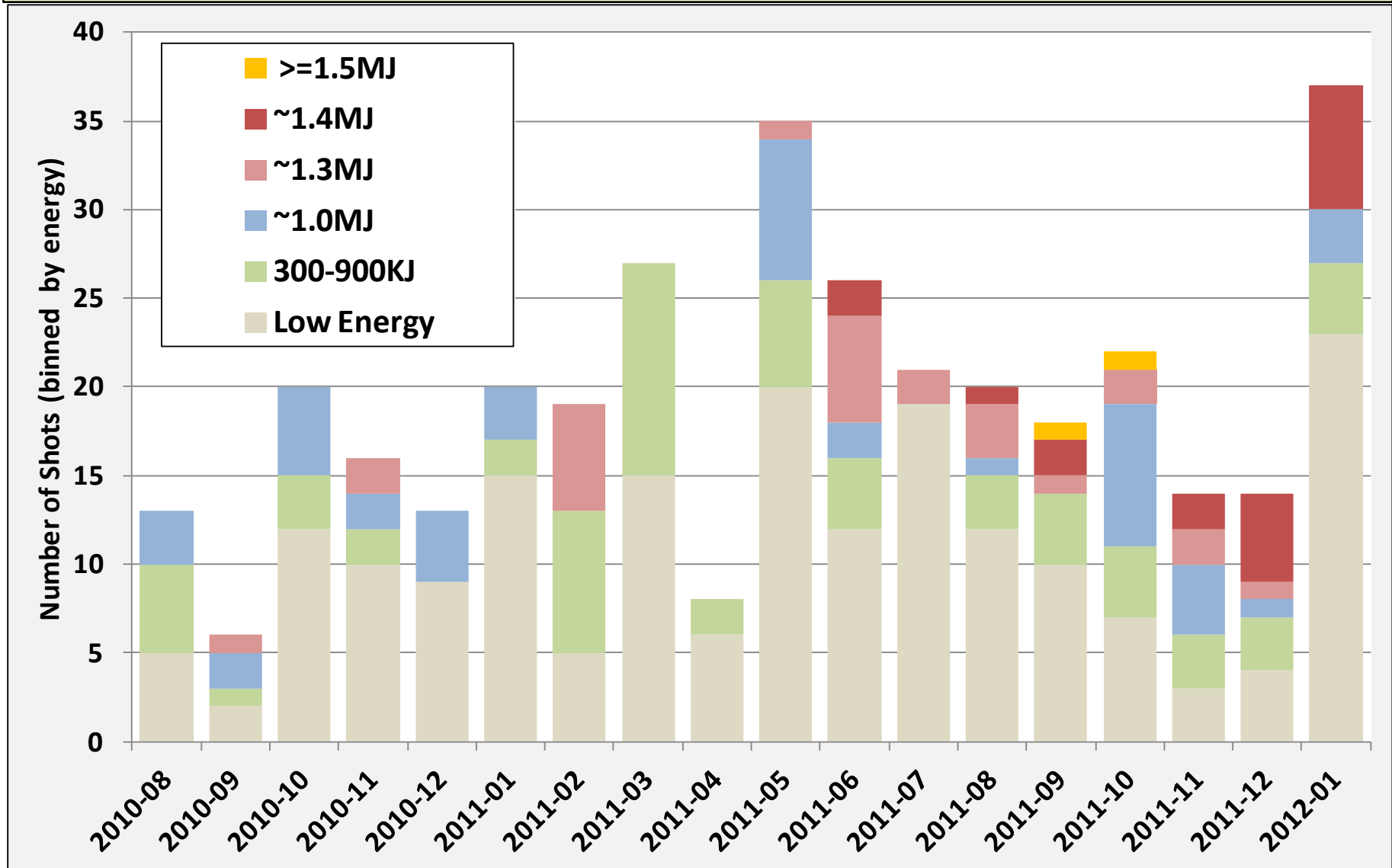
The NIF laser has increased the energy and power on target since its initial commissioning

Time history of 3ω target shots from 2009 to present

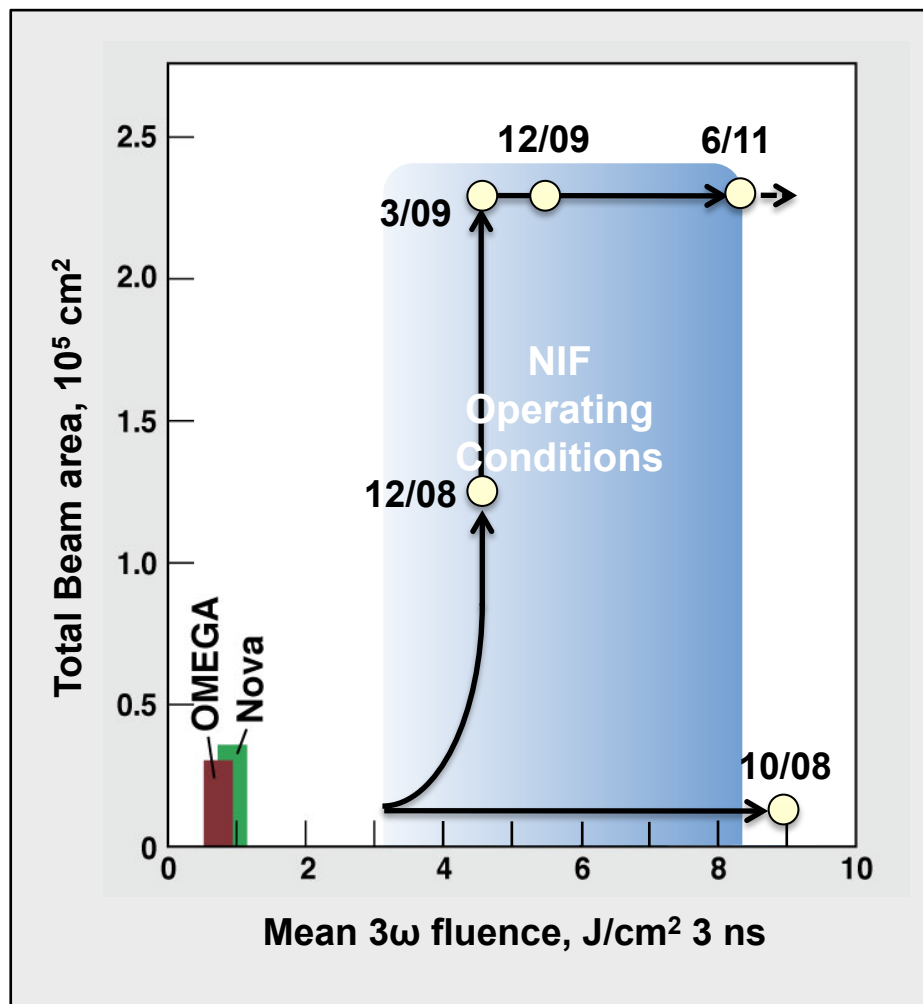


The NIF laser has increased the energy and power on target since its initial commissioning

NIF 3 ω target shots/month and energy from August 2010 to present



The NIF laser has demonstrated its 1.8 MJ design fluence on 192 beams



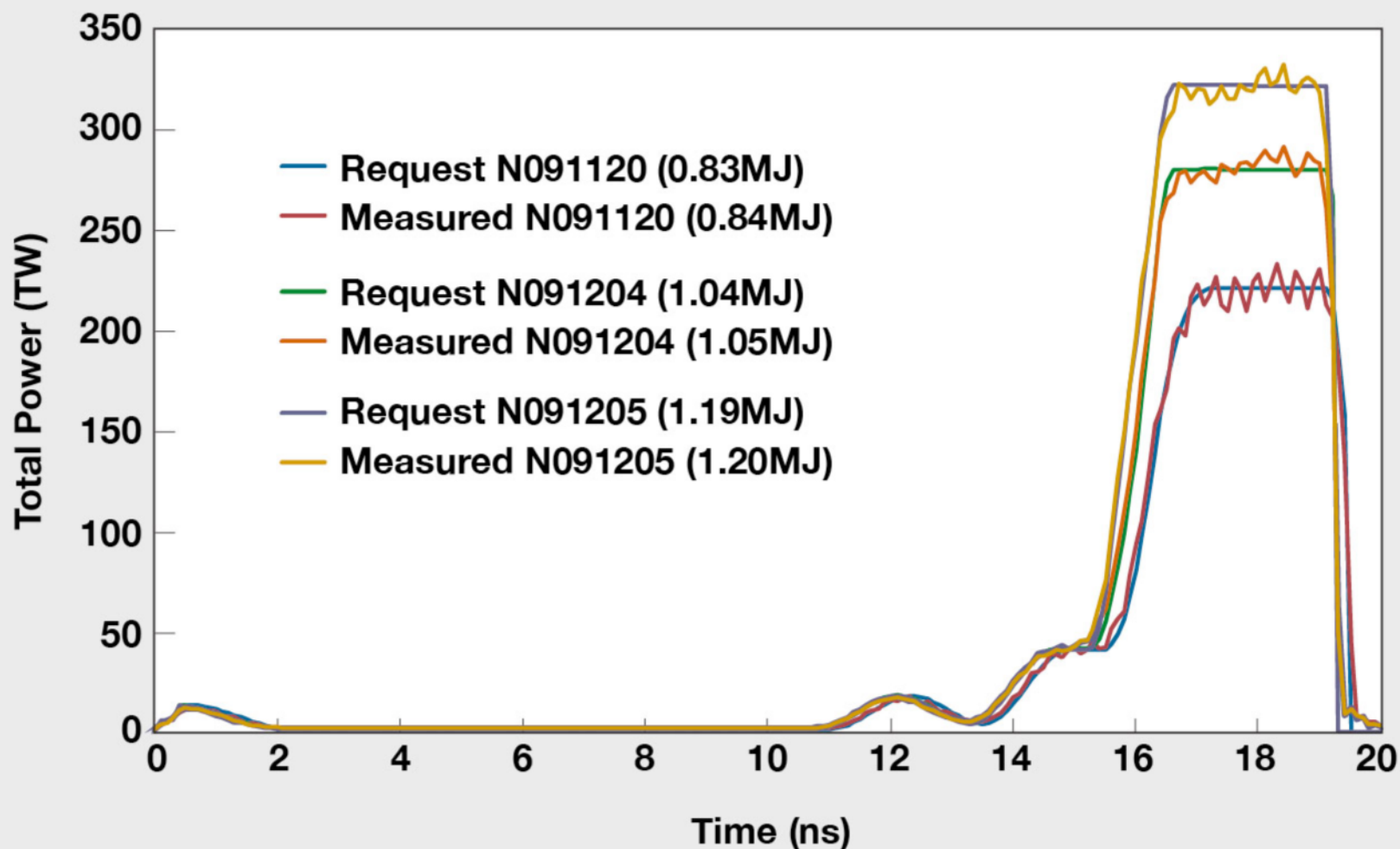
- The NIF 3ω energy specification of 1.8 MJ requires an order of magnitude increase in operating fluence (energy/area) beyond that of previous ICF lasers
- The energy specification and design fluence were defined for a 20.5 ns ignition pulse with damage-equivalent Gaussian pulse duration of 3 ns¹
- In June 2011 NIF operated all 192 beams at its 3ω design fluence²
 - 7.2 J/cm² in a 21 ns ignition pulse with damage-equivalent Gaussian pulse duration of 2.1 to 2.3 ns
 - 8.3 J/cm² scaled to 3 ns

1. NIF Laser System Performance Ratings, Proc. SPIE 3492, 1998.
2. Shots N110620-002 & N110630-001

We met the NIF design 3ω fluence requirements and will keep on increasing the 3ω energy to support experimental goals. Selected beamlines have also been operated at an energy of 1.8MJ Full NIF Equivalent (FNE = single beamline * 192)

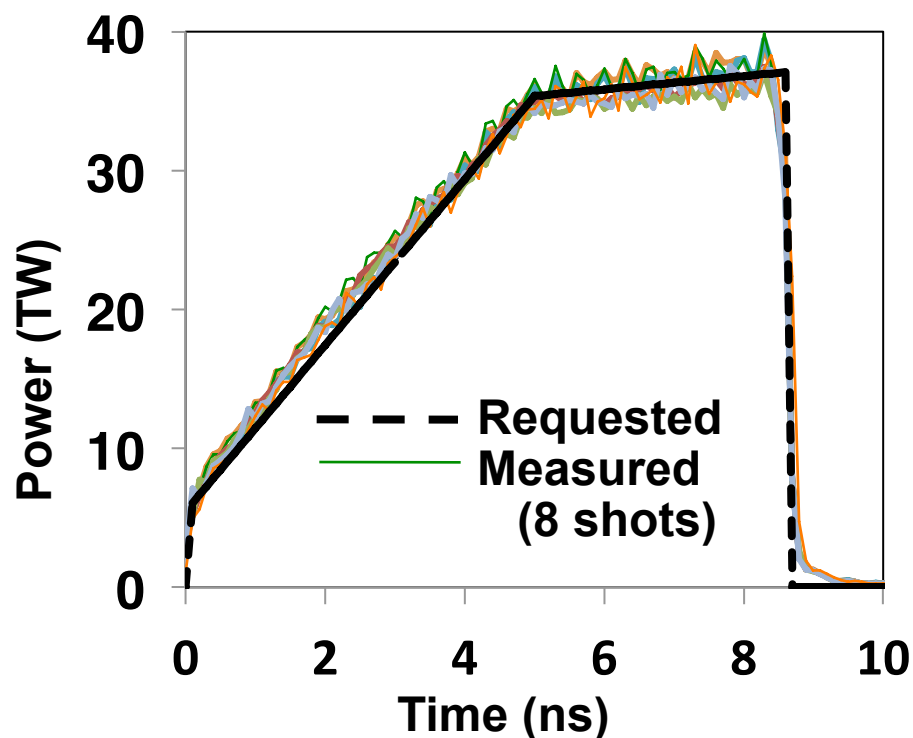
NIF has shown excellent ability to obtain the desired pulse shape and energy

Three ignition pulses of increasing energy between 0.84MJ and 1.2MJ



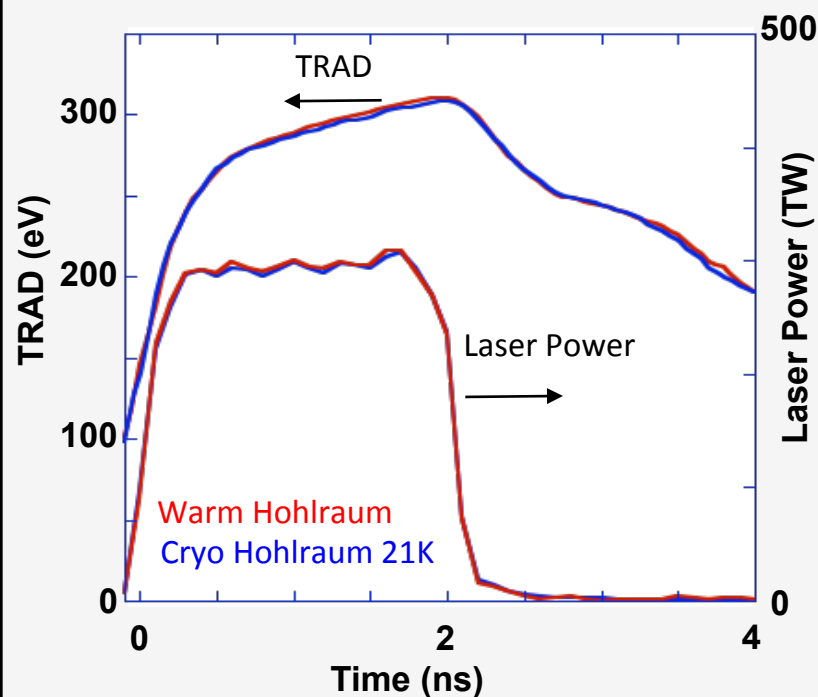
NIF has shown excellent shot to shot reproducibility

NIF delivered the requested pulse shape and energy



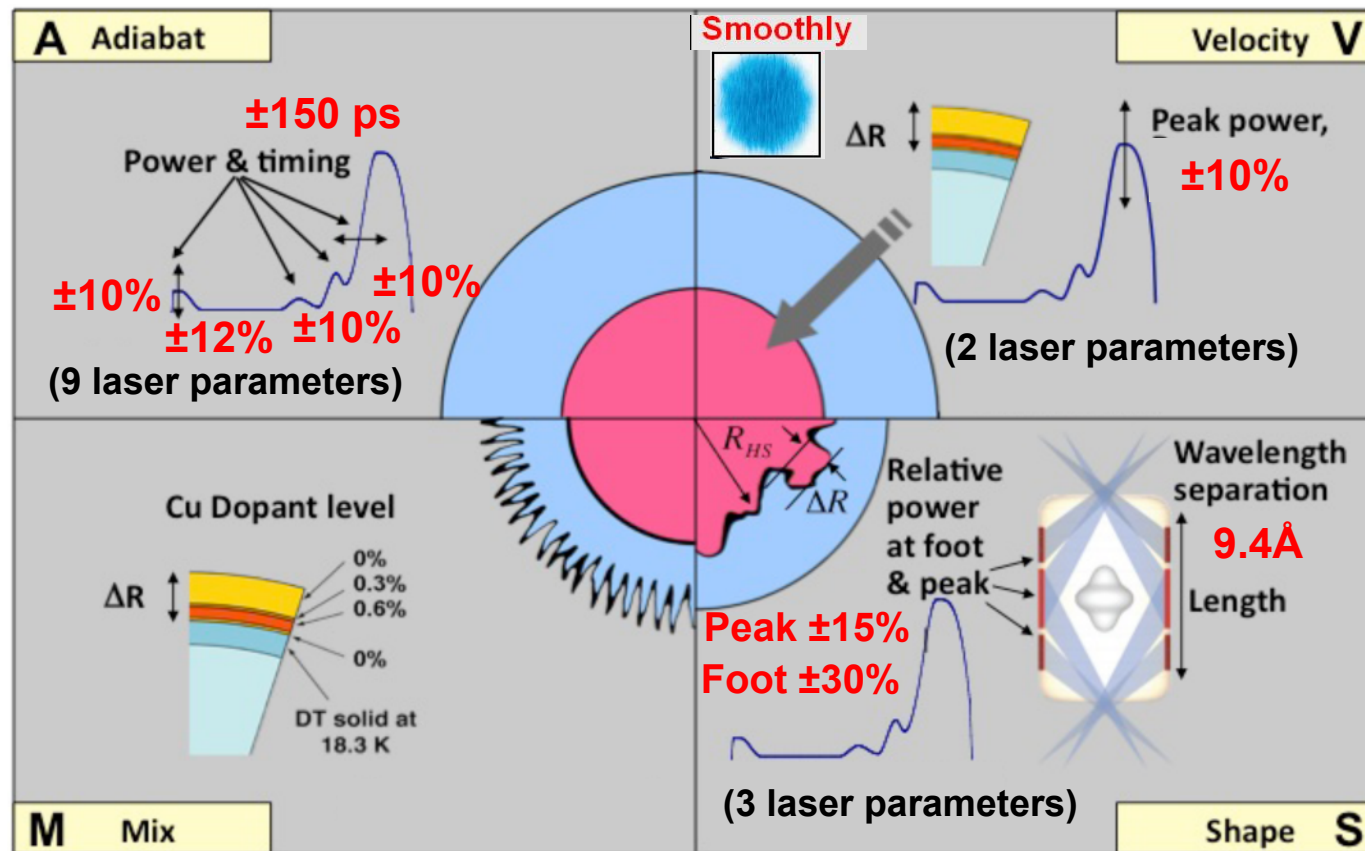
8 shots over a period of 2 months demonstrated high reproducibility

First laser-heated cryogenic hohlraums that perform like warm hohlraums



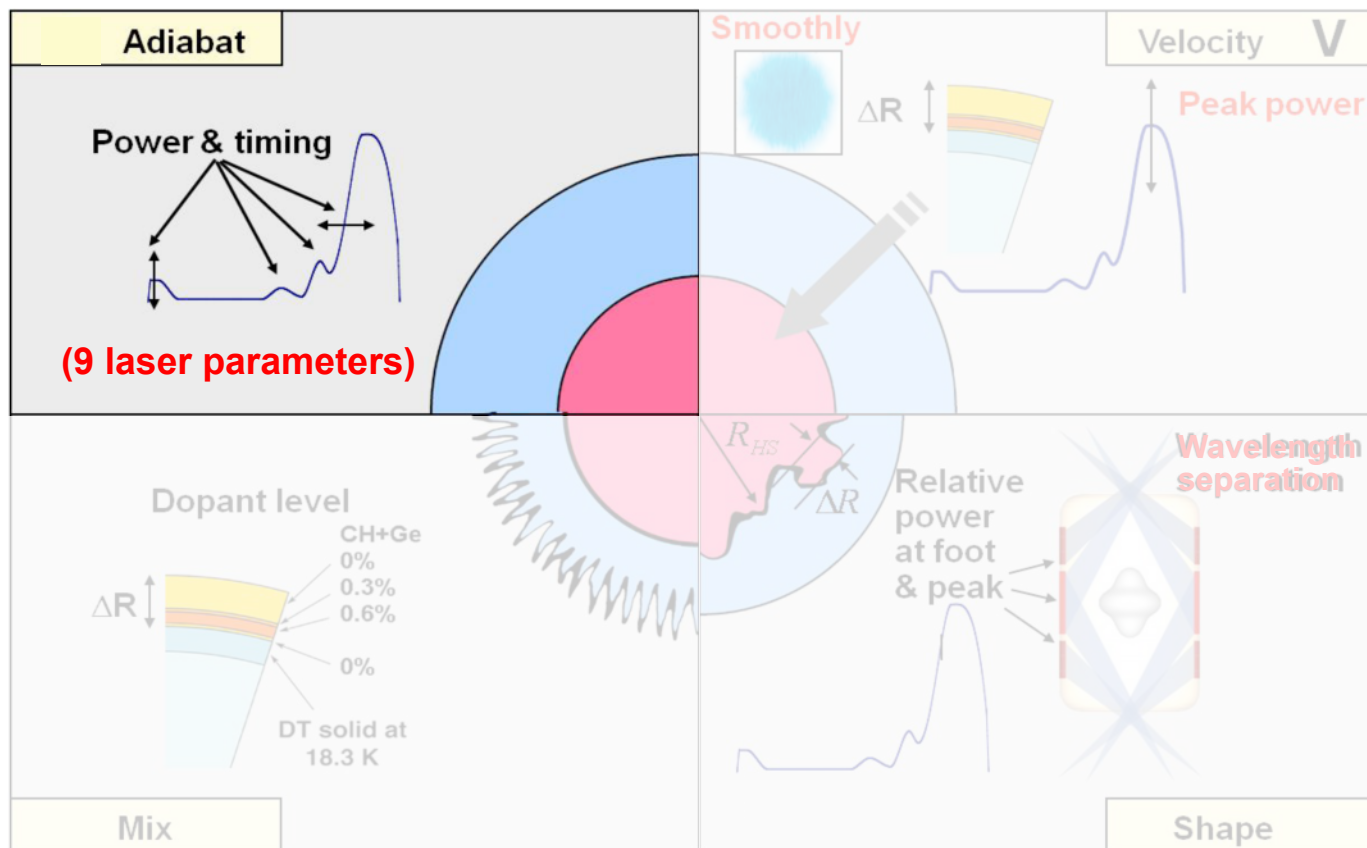
Excellent reproducibility of power and TRAD have been demonstrated

Laser performance is critical for tuning campaigns designed to reach ignition



Today's talk will focus on the NIF's demonstration of these laser capabilities. We plan to continuously improve the NIF laser to increase performance, reliability, and shot rate.

Adjusting laser parameters to optimize adiabat



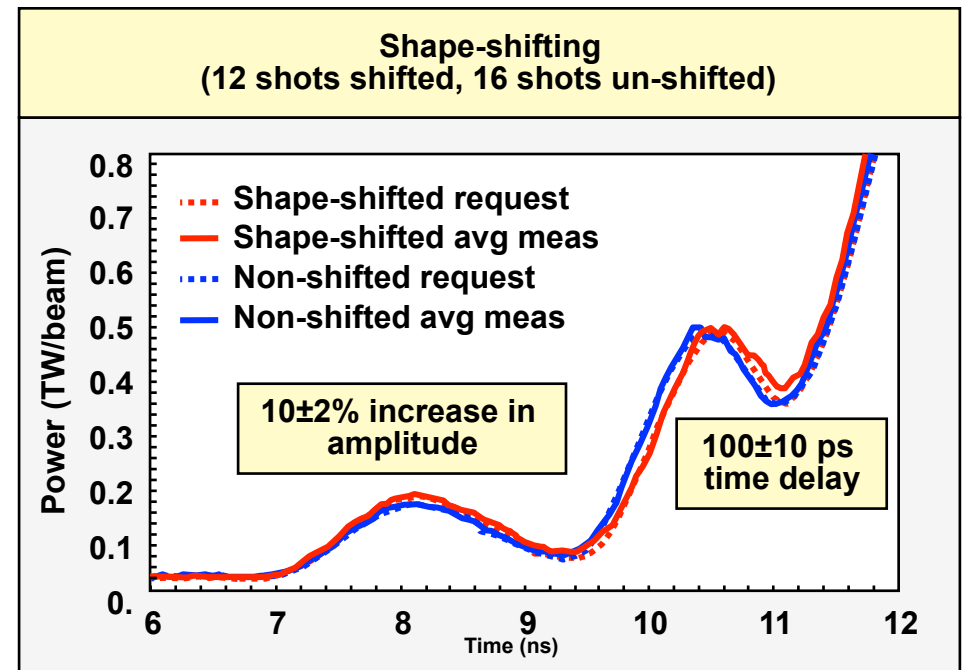
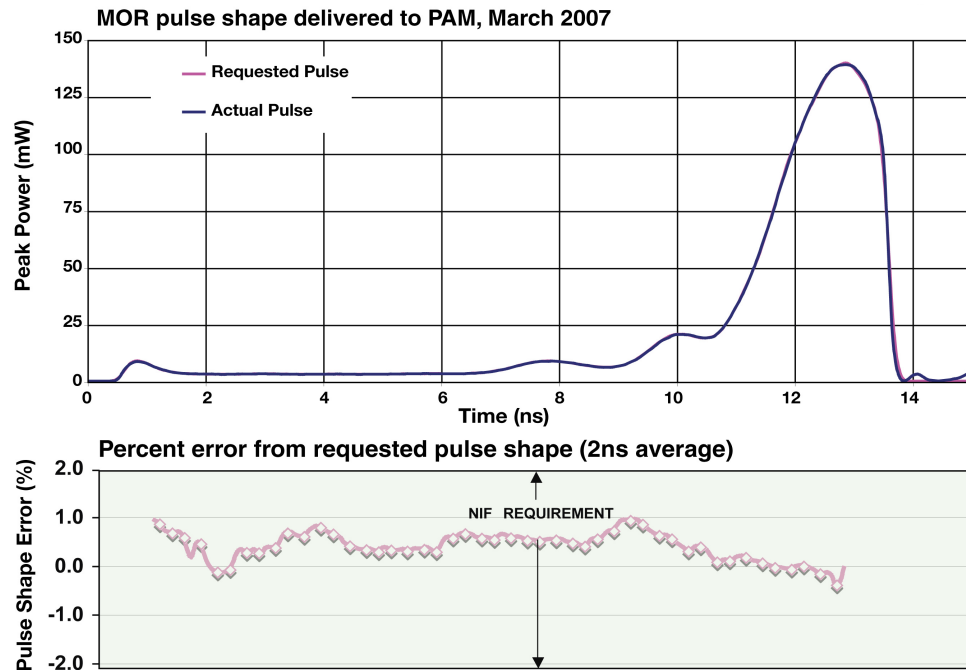
- **Adiabat optimization requires adjustment of:**
 - Power
 - Timing

First will discuss laser parameters required for Adiabat Optimization

The NIF Master Oscillator Room has supported 2107 System Shots to date

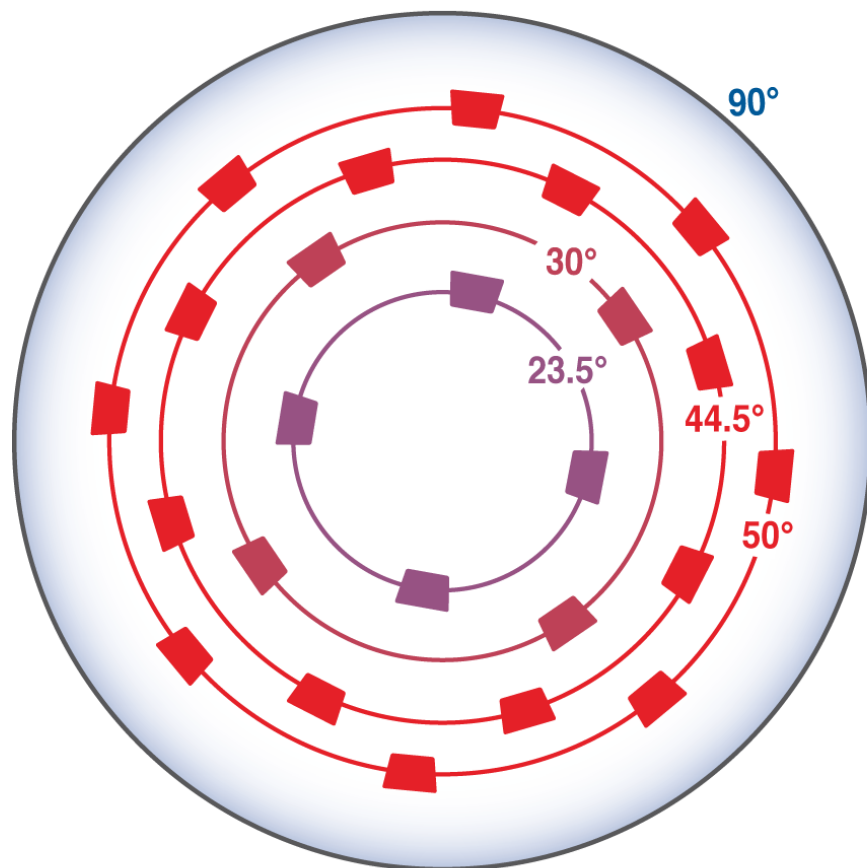


We demonstrated the type of precision adjustments to the pulse shape required for shock timing

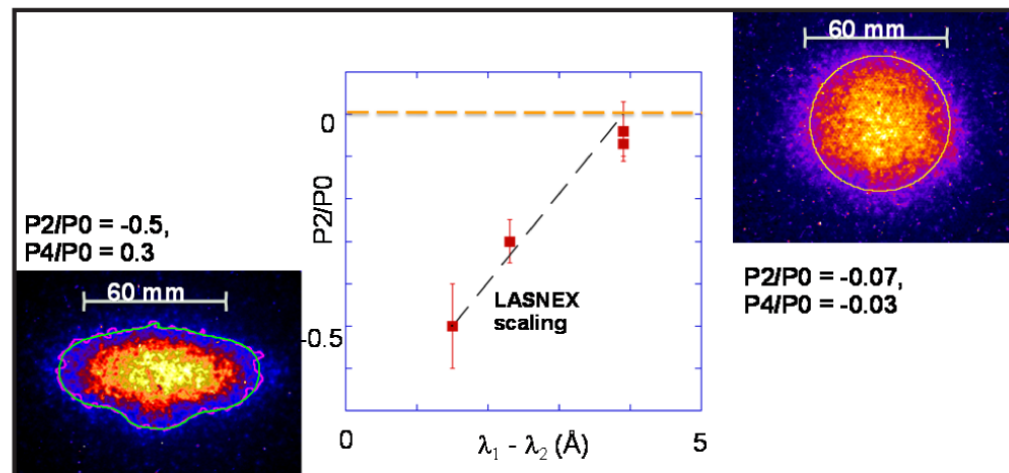


Two-color tuning allowed us to adjust a “pancake” implosion to round without changing laser cone fraction

Top view of NIF target chamber quad position

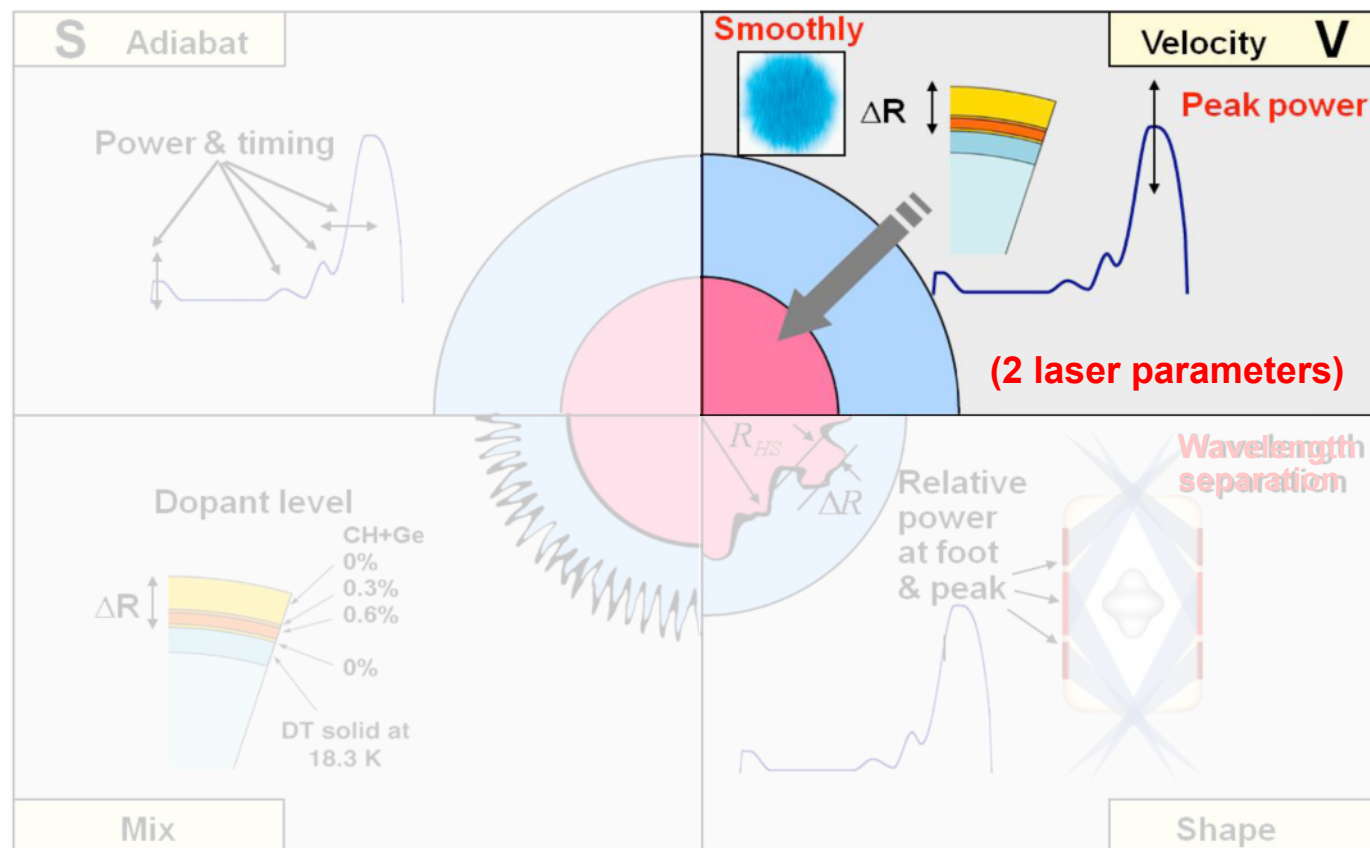


- 23.5° is λ_{1a}
- 30° is λ_{1b}
- 44.5° and 50° combined are λ_2



NIF routinely uses three separate colors for the 23.5° (λ_{1a}), 30° (λ_{1b}), and combined 44.5° & 50° (λ_2) cones

Adjusting laser parameters to optimize velocity

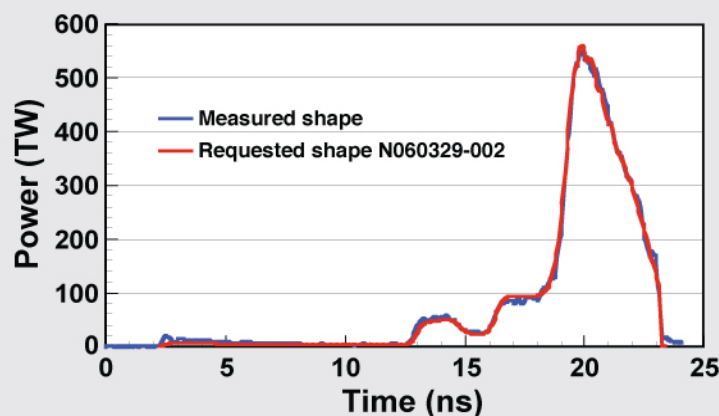


- **Velocity Optimization** requires adjustment of:
 - **Peak Power**
 - **Focal spot smoothing** (measured in the Precision Diagnostics System – PDS)

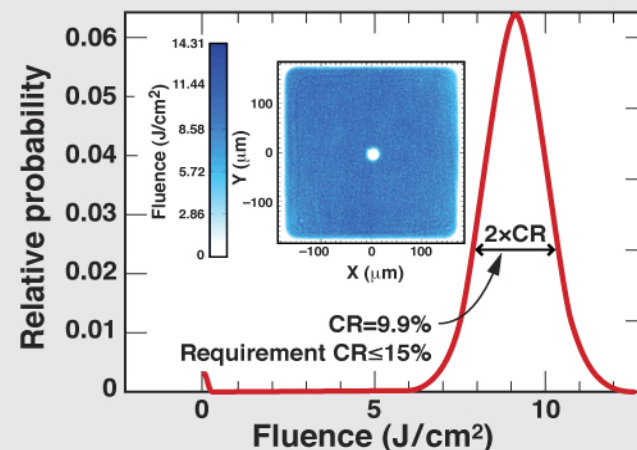
Next discuss laser parameters required for Velocity Optimization

Achieving a small intensity focal spot at high peak power is a necessary precursor to focal spot smoothing

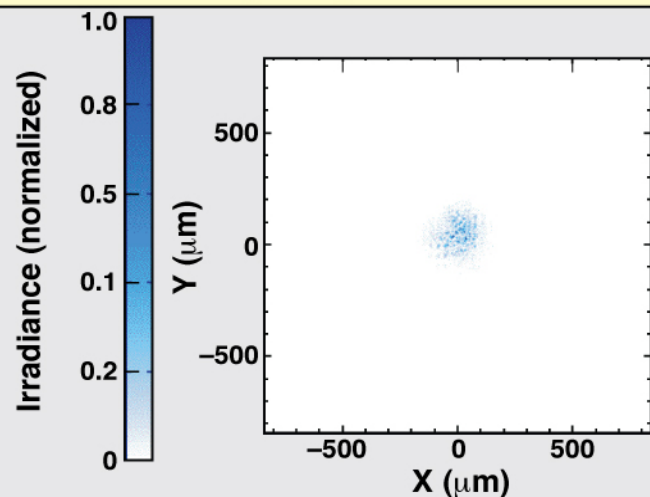
3ω Pulse Shape (540 TW)



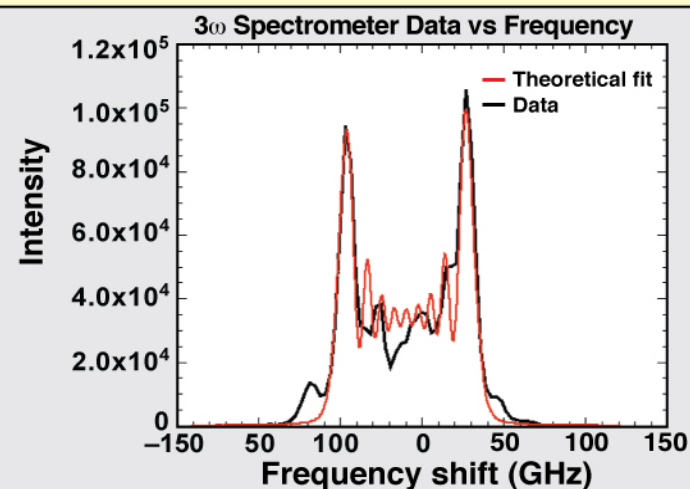
3ω Near Field Profile



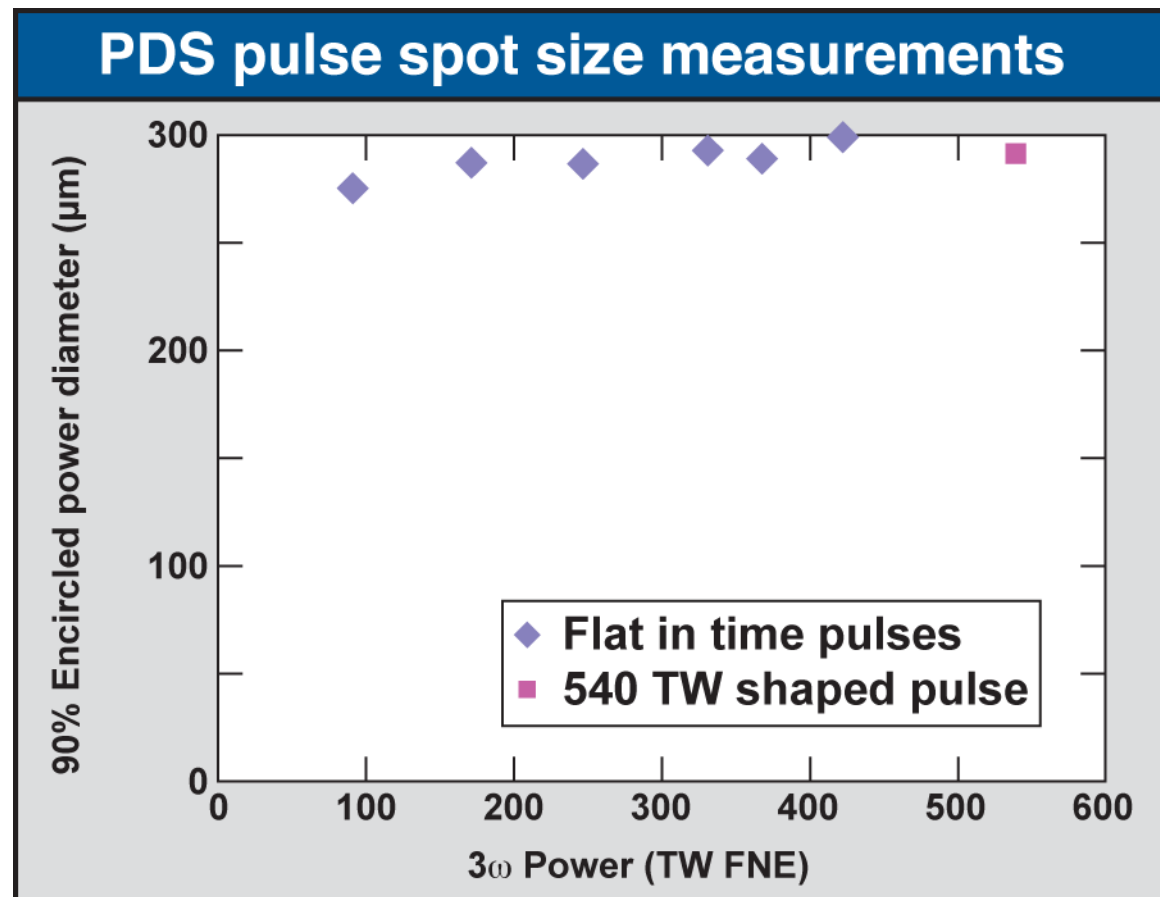
3ω Focal Spot (0.145 mm FWHM)



3ω Spectrum (90 GHz SBS only)



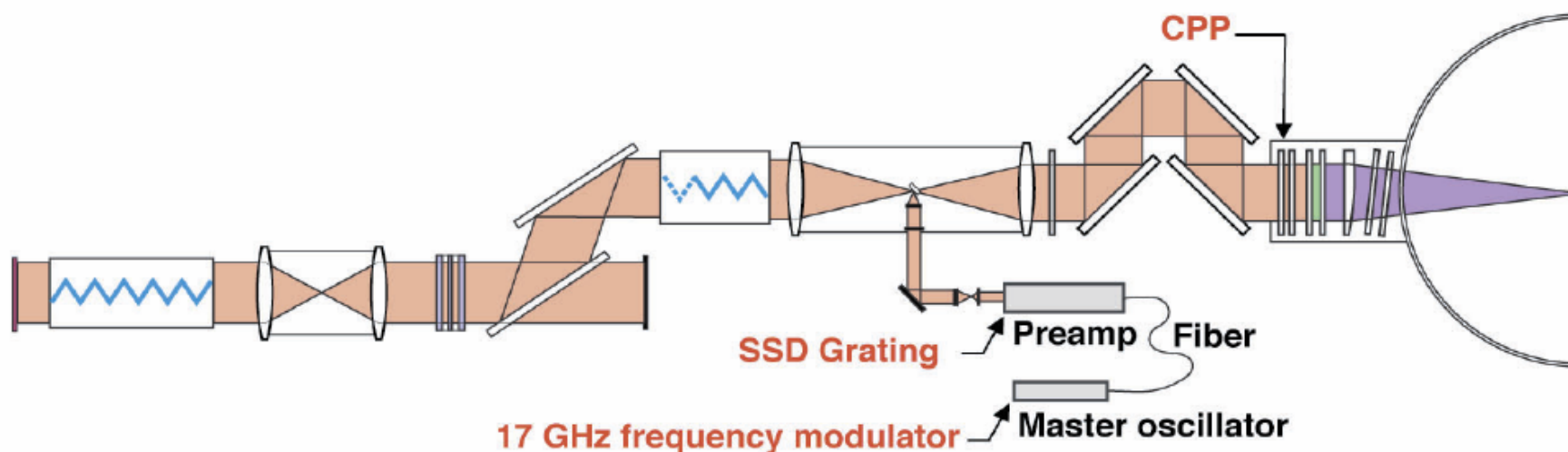
The inherent NIF spot size is very weakly dependent on peak power



- Beam profile at the target is stable on NIF because non-linear propagation effects are held in control all along the beamlines
 - ΔB held to <1.8 radians
 - High optical quality of all transmissive and reflective optics
 - Cone pinholes
 - Low air turbulence in enclosed beamlines

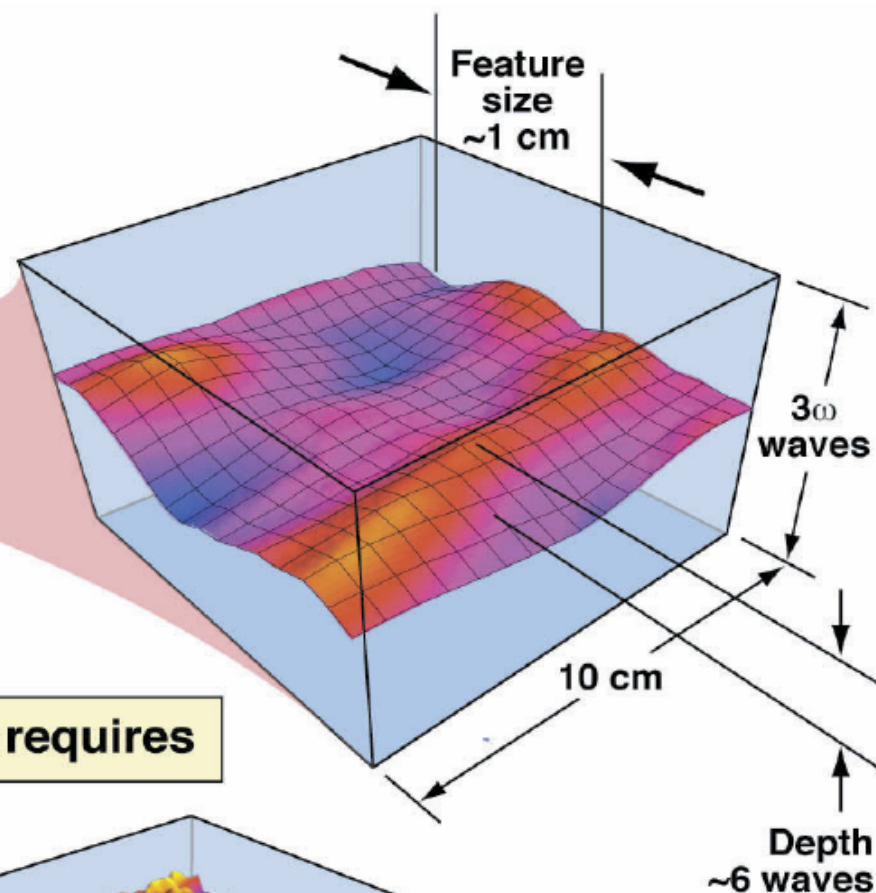
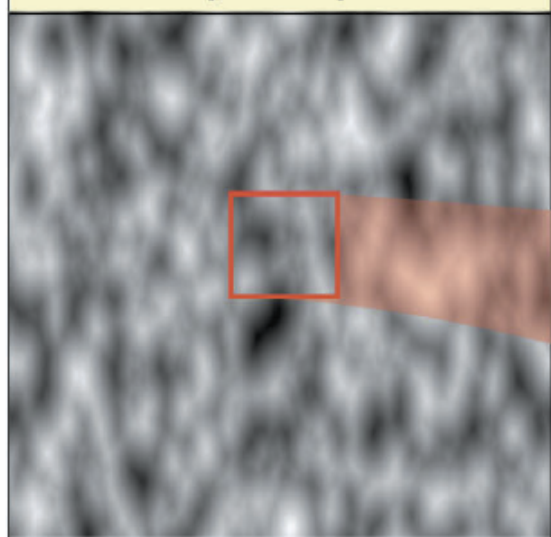
Beam smoothing is used on NIF

- Without beam smoothing, at its focus at TCC, the NIF laser produces a small, high contrast (100%) intensity profile
- Beam smoothing is used to reduce the intensity of the spikes, lower the contrast and shape the beam in a manner that meets target size and irradiance requirements

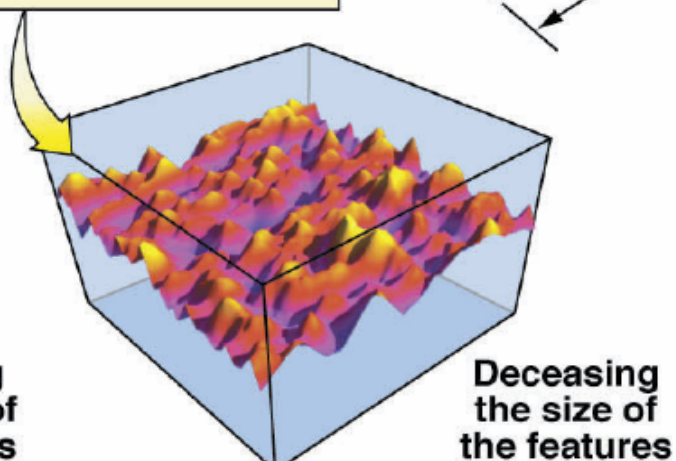
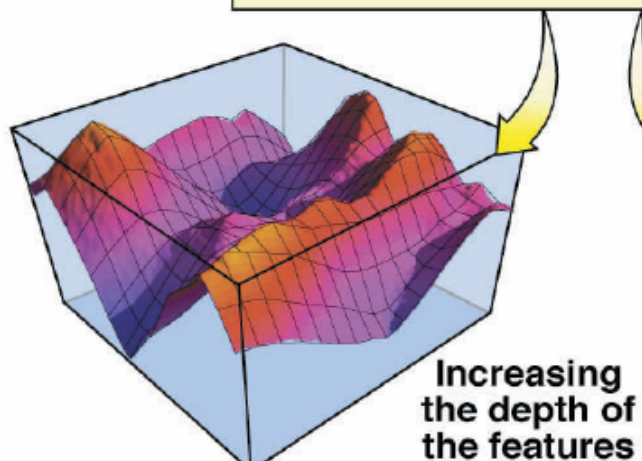


A continuous phase plate (CPP) is a continuous aggregation of small lenses

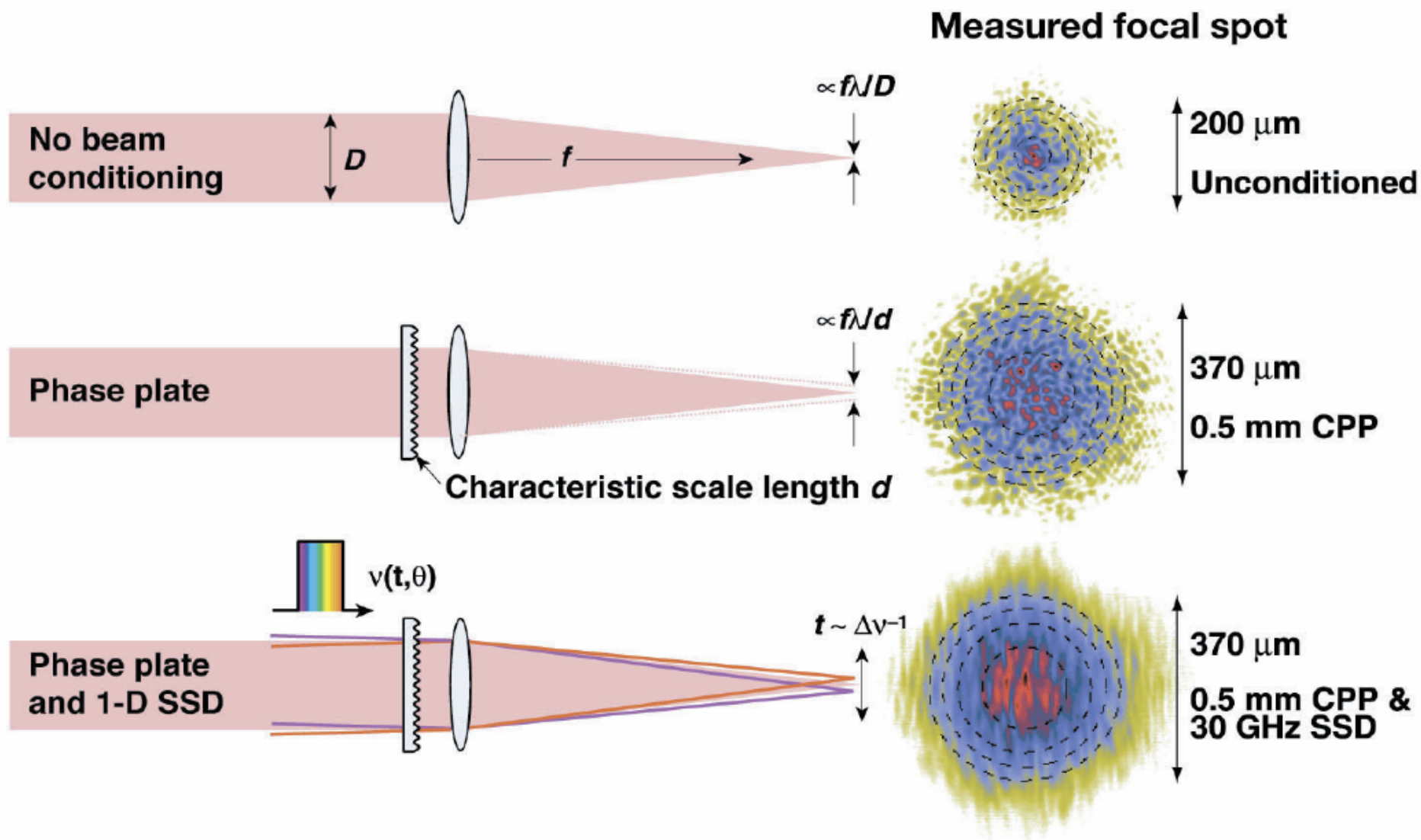
1 ω CPP for a 1 mm X 0.6 mm elliptical spot



Increasing spot size requires

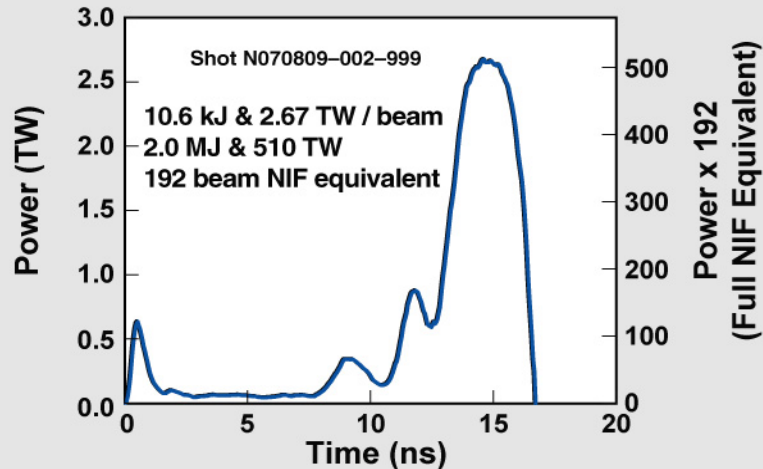


Beam conditioning is used to improve the focal spatial uniformity of the laser focal point

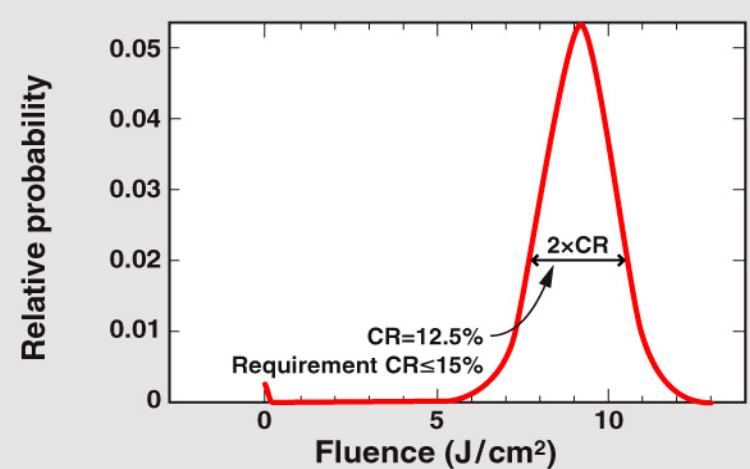


PDS measurement at 1.8MJ of simultaneously meeting point design beam conditioning, energy, temporal profile, and peak power requirements

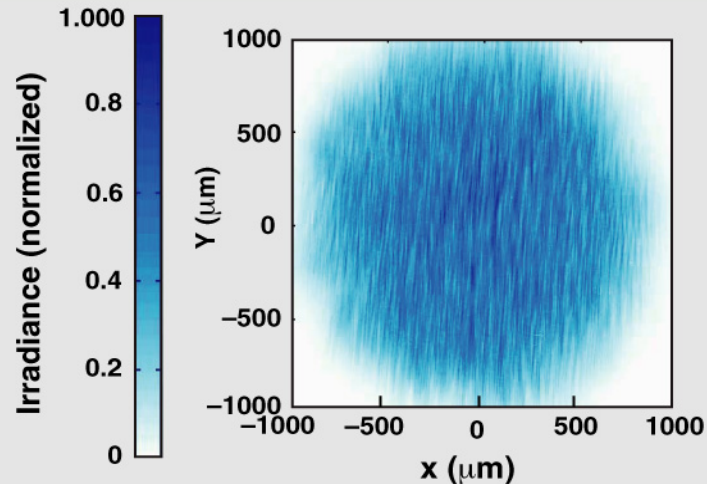
3ω Pulse Shape (2 MJ & 510 TW)



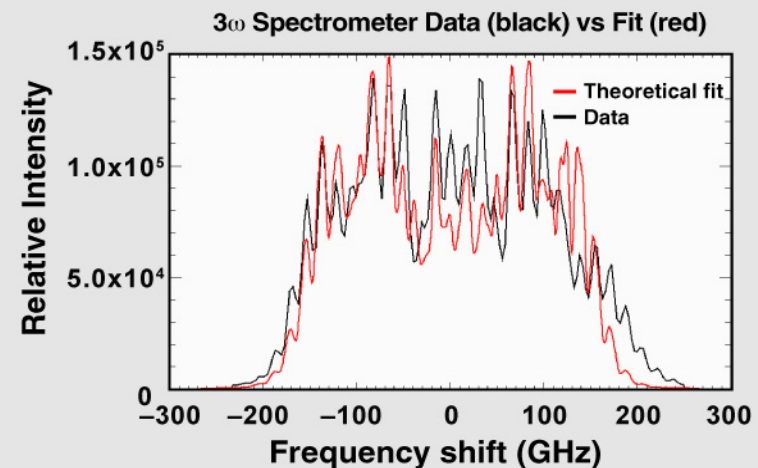
3ω Near Field Fluence Histogram



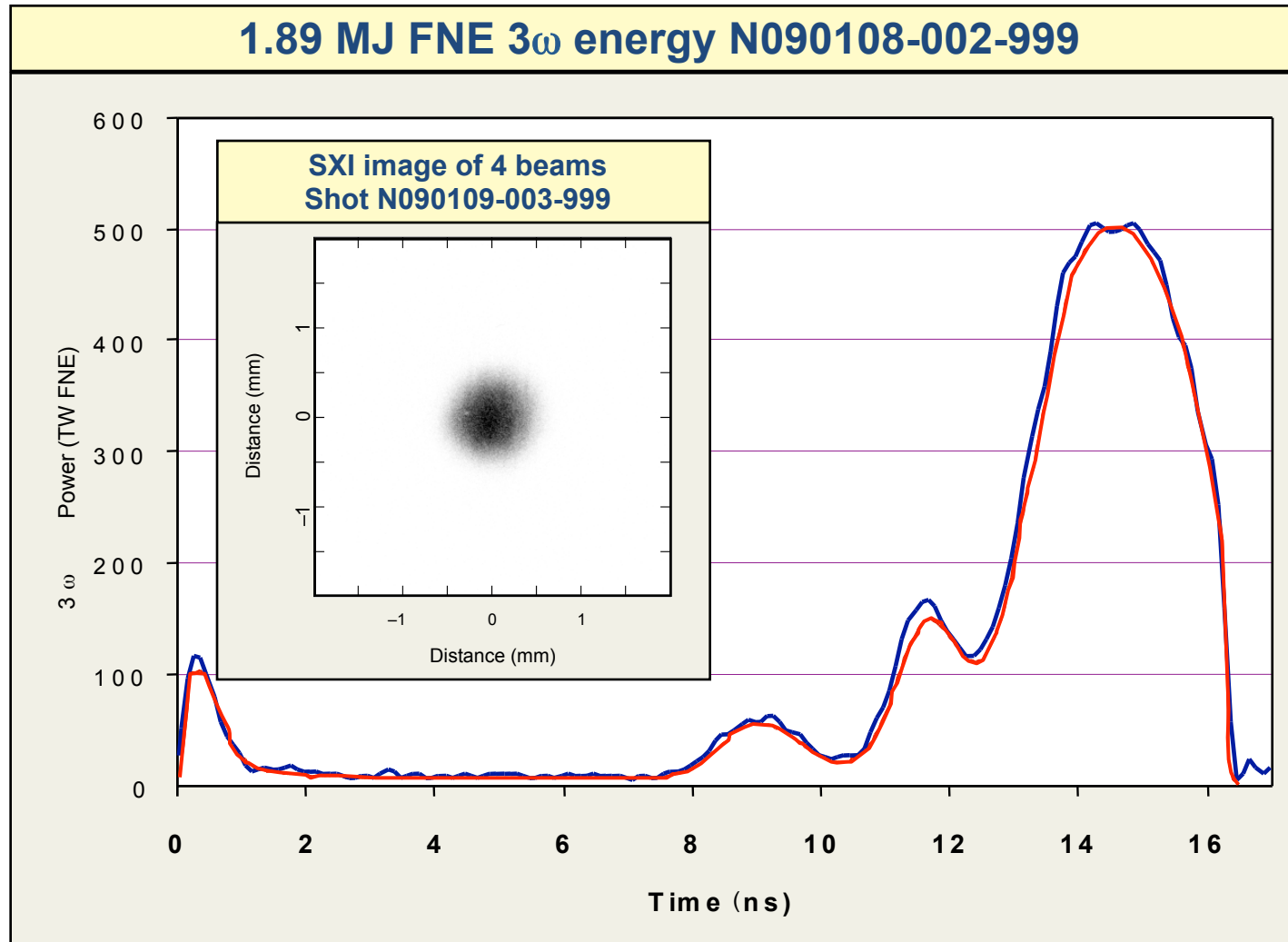
3ω Focal Spot ($1.91 \times 1.64 \text{ mm}^2$)



3ω SSD Bandwidth (270 GHz)

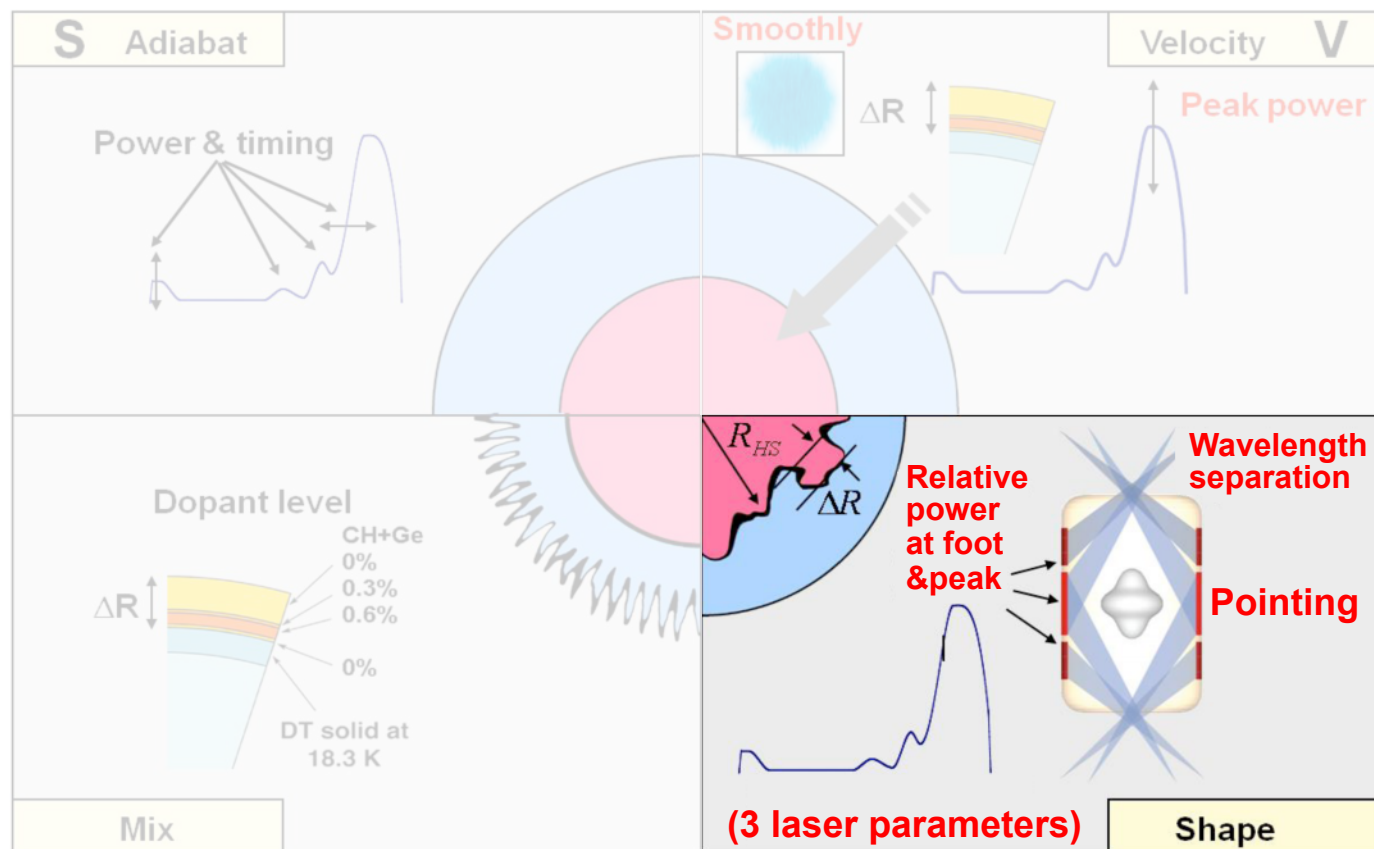


One quad of the laser was used to demonstrate the full NIF energy at 3ω delivered to the designer-specified focal spot with all smoothing methods used simultaneously



- Energy and power on Q34B are multiplied by 48 quads to obtain FNE

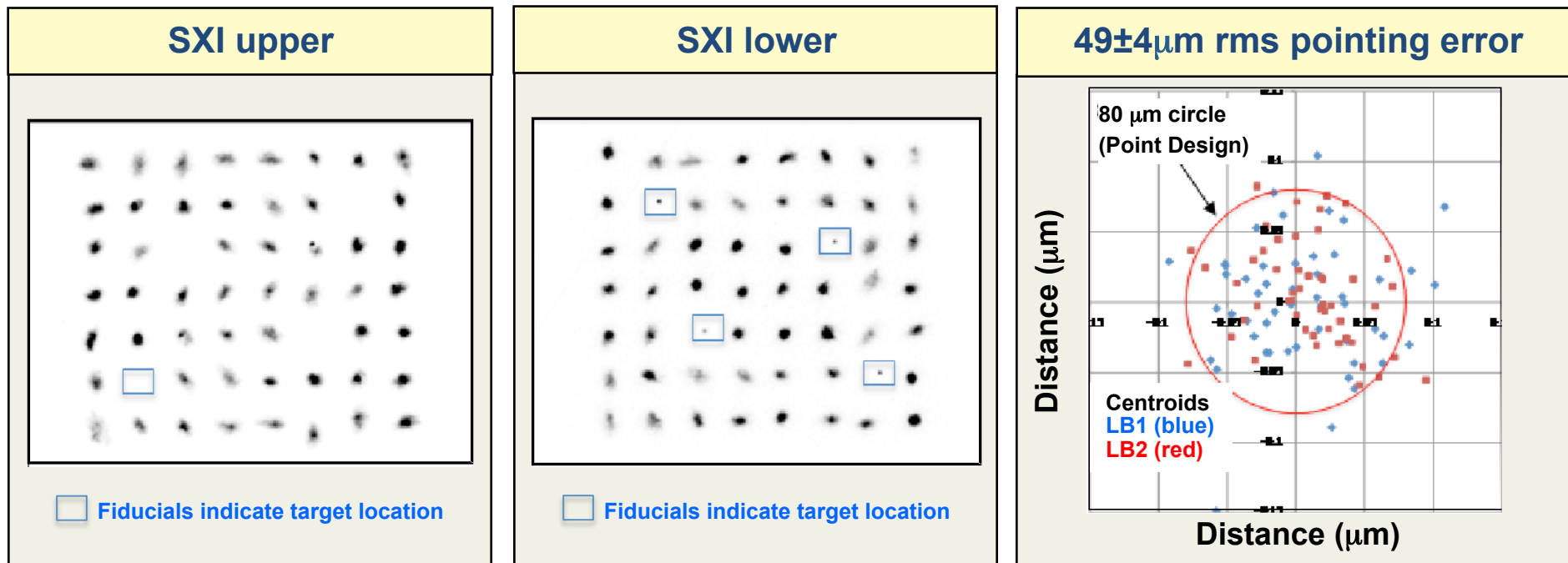
Adjusting laser parameters to optimize shape



- Pointing accuracy
- Shape Optimization requires adjustment of Relative Power at the foot and peak of the laser pulse
 - Synchronization
 - Power Balance
- Wavelength separation

Next will discuss laser parameters required for Shape Optimization

Pointing stability was measured on 96 beams (plus 8 fiducial beams) delivered to a flat target with two SXIs

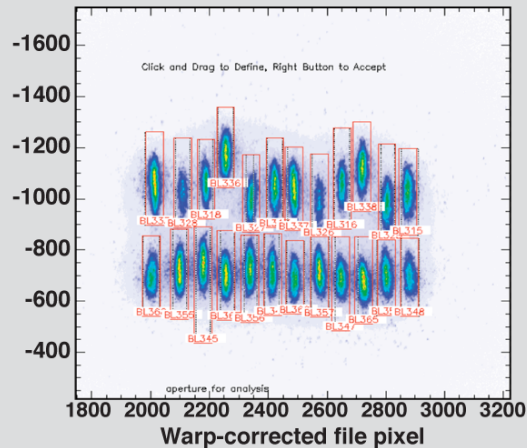


700 microns between focal spots on new TAS camera
Shot N100622-001-999

- 8 beam (single bundle) pointing shot completed 12/08
- Two 96 beam pointing shot series were performed
 - 1st demonstrated beam to target pointing was 64μm rms (1/09)
 - 2nd demonstrated beam to target pointing was 49±4μm rms (6/10)
 - Result includes post-shot TAS calibration correction for lower beams

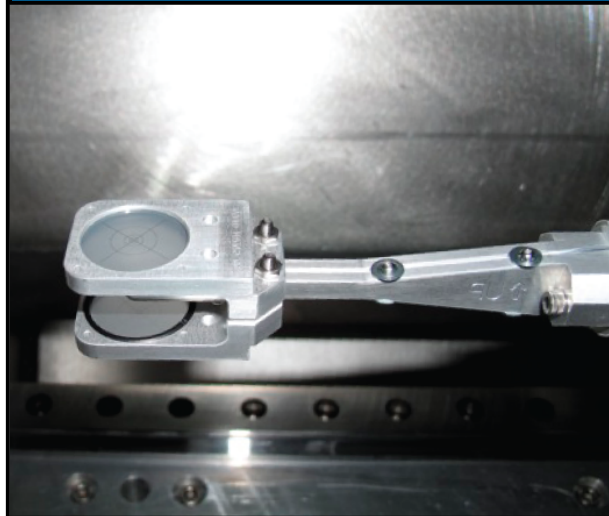
Pulse synchronization at Target Chamber Center (TCC) is well within 30 ps RMS requirement

Rough synchronization verified in 2009 with the SXD-B streak camera



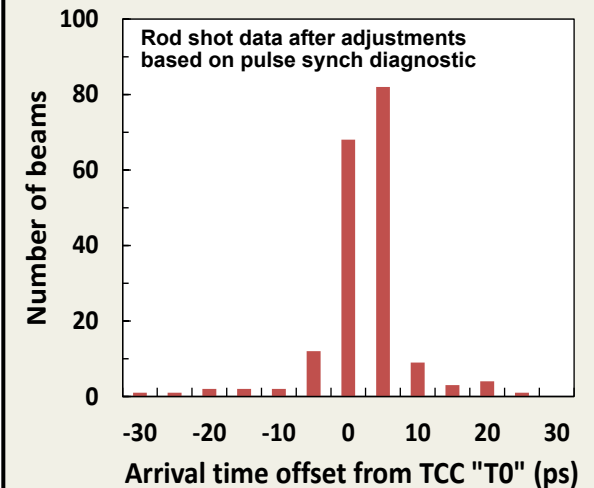
37 ps rms

New diode-base pulse synchronization diagnostic commissioned in 2010



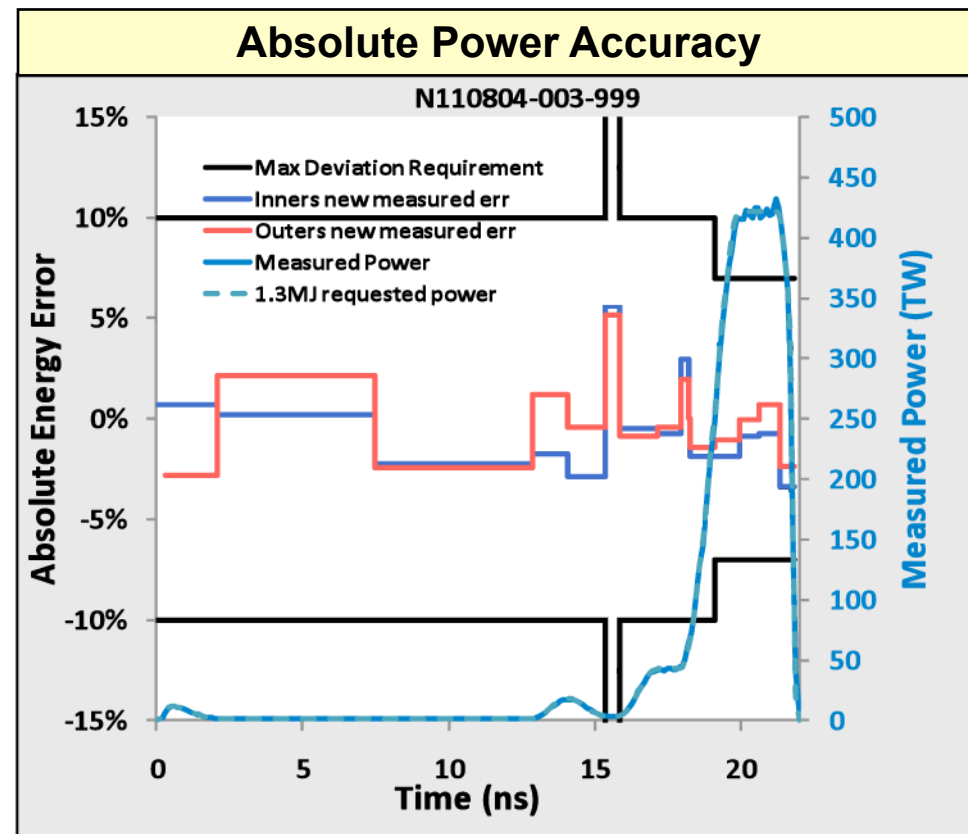
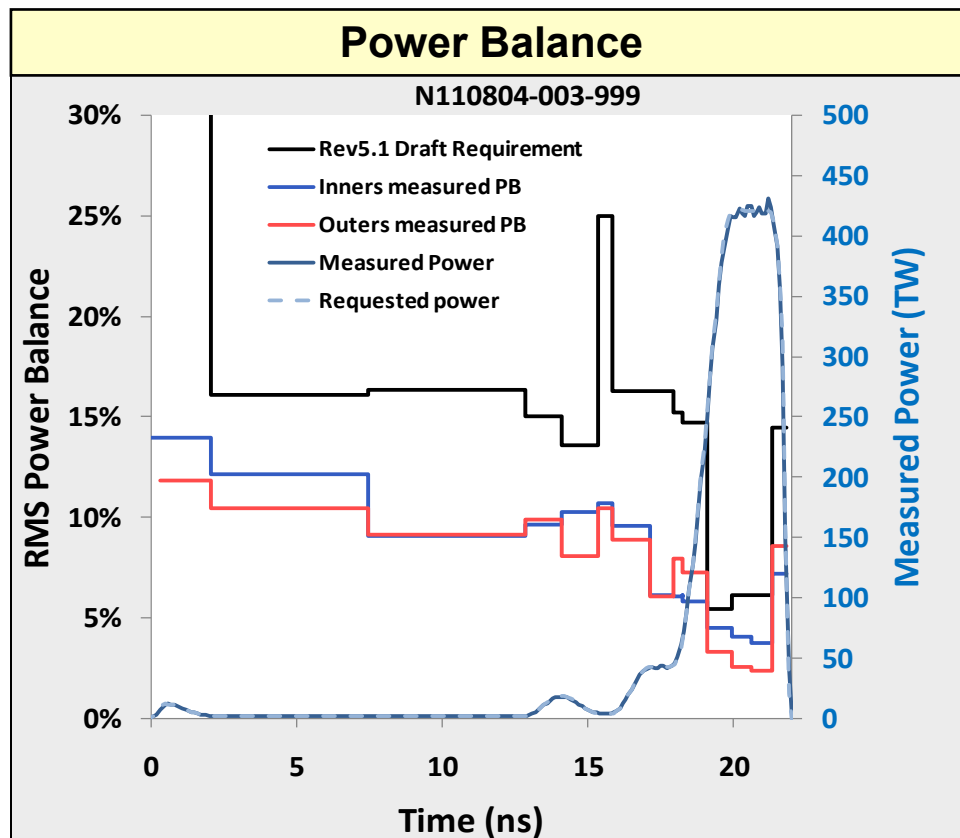
Resides at TCC and measures 192 beams in a few hours with <8 ps resolution

Improved synchronization measured in May 2011



~7 ps rms relative to fiducial MOR pulse shaping adds an additional 18 ps rms

We routinely meet the Ignition Point Design power balance and accuracy specifications



Summary

- **NIF is a flexible laser platform**
 - **NIF has a wide range of shaped and Flat-in-time pulses**
 - **Duration = 0.5ns to 30ns**
 - **Demonstrated energy and power = 1.6MJ, 435TW (192 beams)**
 - **Routine Quad pulse delays = 30ns – laser pulse width¹**
 - **NIF routinely generates short impulses on all quads**
 - **Duration = 88ps gaussian (FWHM)**
 - **50J and 0.54TW per beamline**
 - **Routine Quad pulse delays = 20ns**
 - **Inner and outer cone wavelength separation of up to 9.4A**
 - **Focal spot size is adjustable using continuous phase plates**
- **NIF is a precise laser platform**
 - **Demonstrated pointing of <50 μ m RMS**
 - **Demonstrated timing at TCC of < 20ps RMS**
 - **Demonstrated power balance meeting ignition specifications**
- **NIF shots are reproducible in energy and power**

¹Laser pulse width includes postpulse, if a postpulse is required to saturated regenerative amplifier



NIC



Example of laser damage scaling with pulse shape

PROOF COPY 002703APL

1-3 Carr, Trenholme, and Spaeth

Appl. Phys. Lett. 90, 1 (2007)

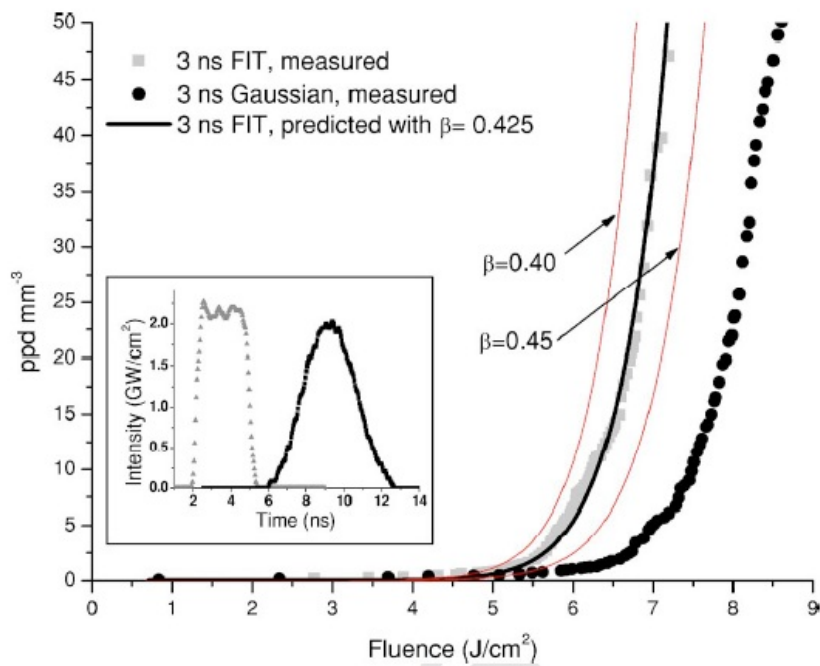


FIG. 1. Measured density vs fluence curves for 3 ns FIT and Gaussian pulses and the density vs fluence curve of a 3 ns FIT pulse predicted from the 3 ns Gaussian pulse data with $\beta=0.425$ and nearby values. The inset depicts the temporal trace of both pulses.

TABLE I. Percentage difference in fluence (Φ) for observable damage by a FIT vs Gaussian pulse.

Sample	$\Phi_{\text{FIT}}/\Phi_{\text{G}}$	β
A	83%	0.4
B ^a	85%	0.425
C	80%	0.37
D	78%	0.35

^aThe pulse shapes and damage vs density curves from this sample are shown in Fig. 1.

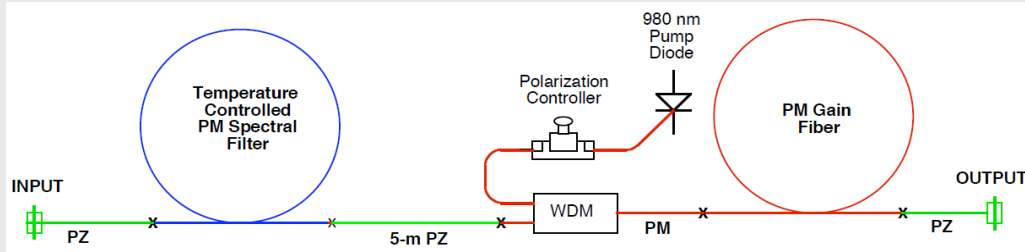
For fluences above the onset of observable damage the density of damage for a given fluence is seen to differ significantly for FIT and Gaussian pulses. The measured data in Fig. 1 as well as the data from the other four samples (see Table I) indicate that the fluence needed to cause observable damage with a FIT pulse of the same FWHM duration is 80% \pm 5% of that needed for a Gaussian pulse.

To apply the model we must adjust our free parameter (β) in Eq. (5) to get the experimentally observed pulse-width dependence. From the model, the ratio of fluences needed to produce the same damage level with FIT and Gaussian

AQ:
#3

AM compensator need and design (2/2)

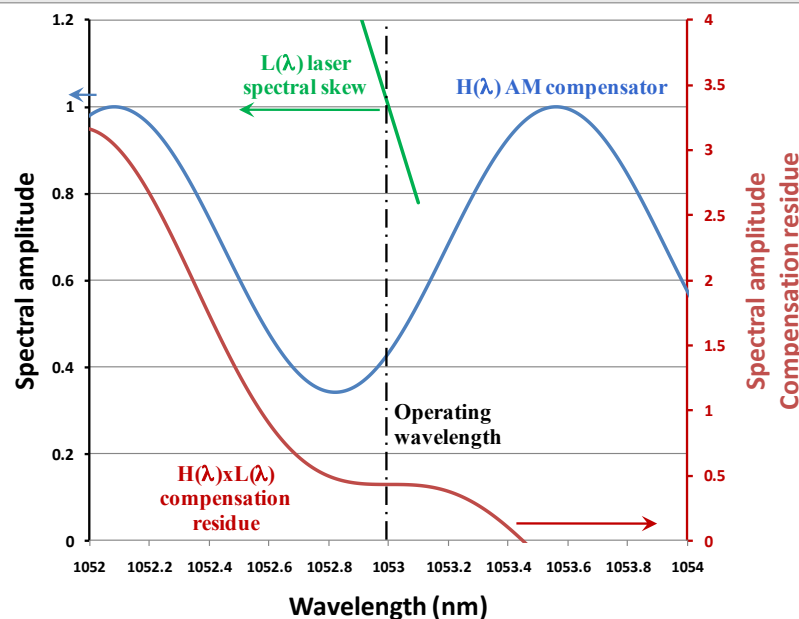
Fibered AM compensator layout



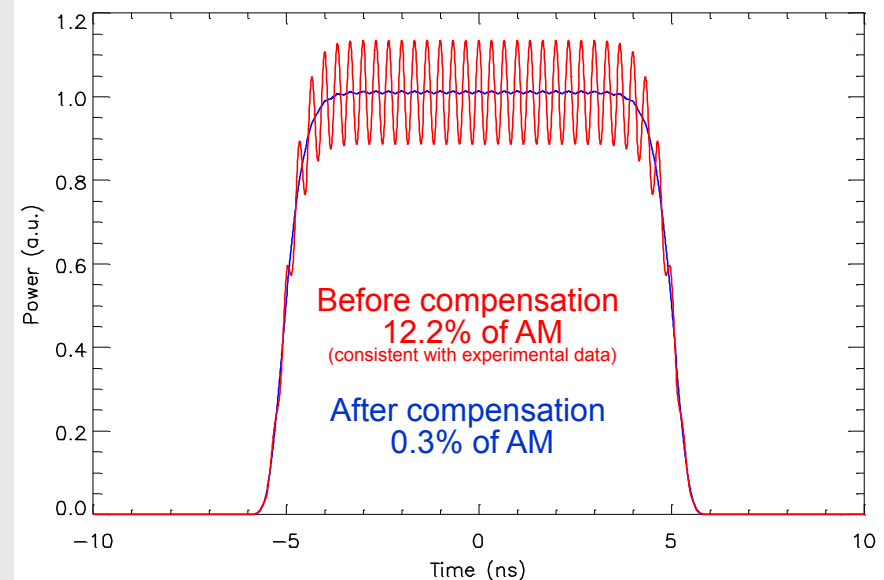
- 1.5 m of HB PM fiber,
- Dispersion between the two axis of the PM fiber $D=1.67$ ps/m leading to a free-spectral range of 1.5nm,
- Filter is tuned with temperature,
- Temperature stability is <0.004 °C,
- Compensation transfer function is given by:

$$H(\lambda) = a + b \cos\left(\frac{2\pi c L D \lambda}{\lambda_0^2} + \phi(T)\right)$$

Example of AM compensator for 2.2 nm^{-1} slope

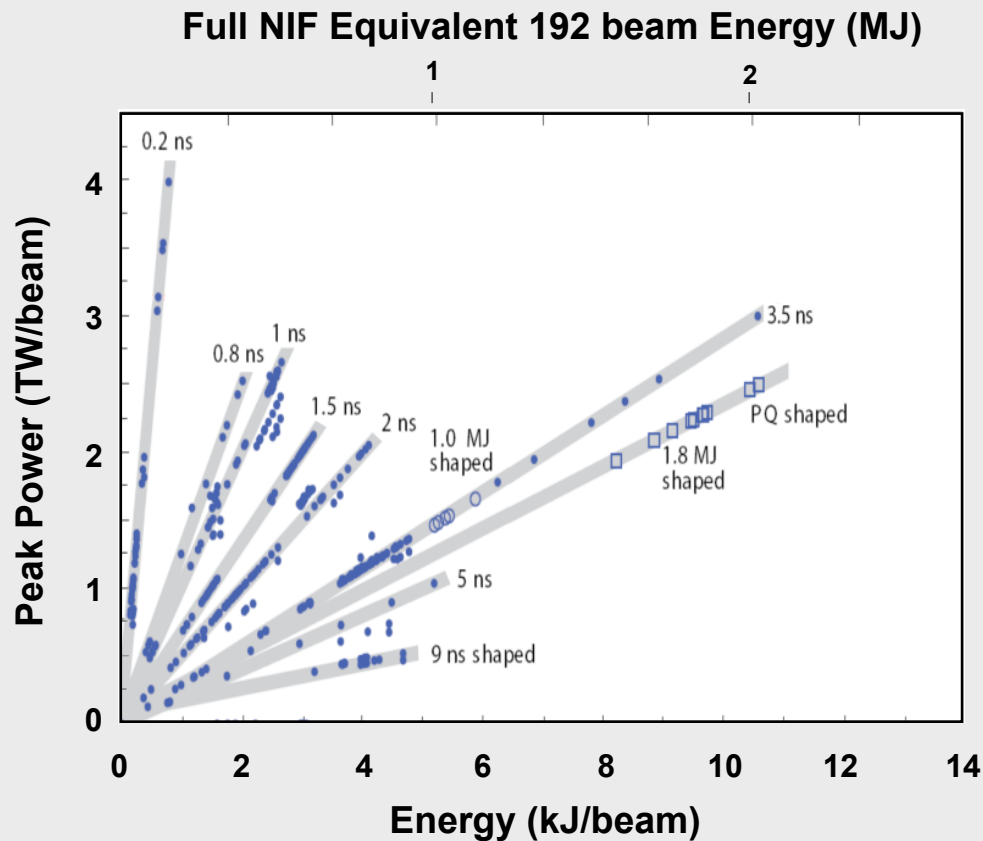


Before / After compensation for 2.2 nm^{-1} slope.
Miró simulation for 30 GHz of SBS.

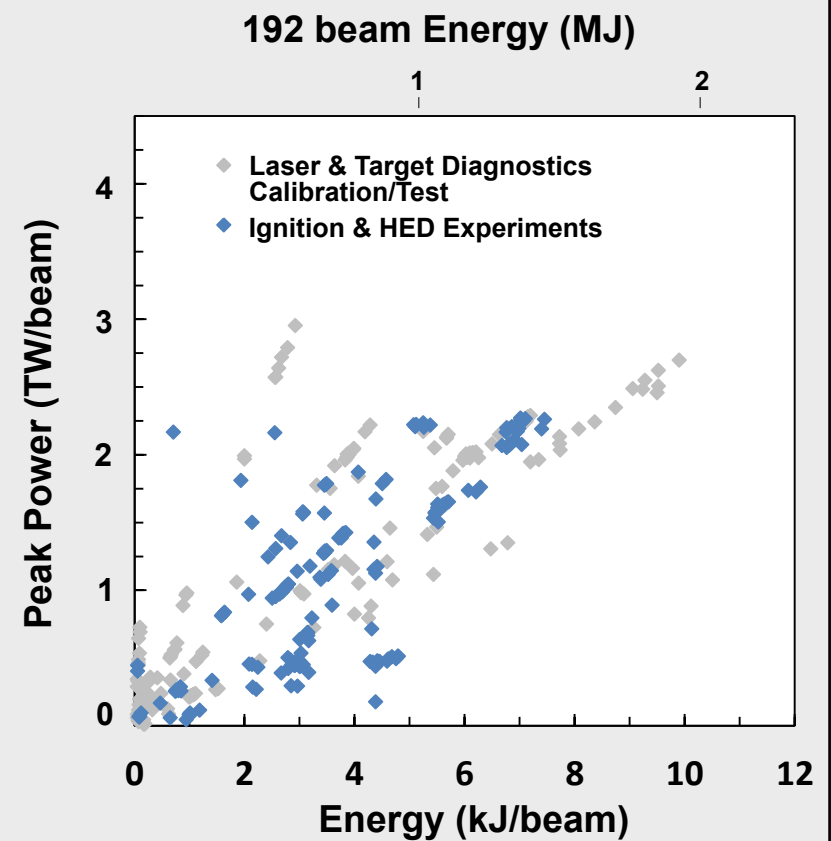


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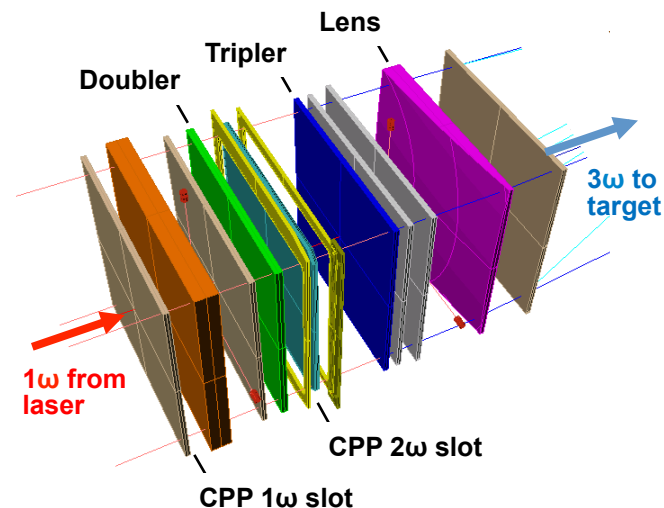
NIF 3ω Experiments June 2009 to Aug 2011



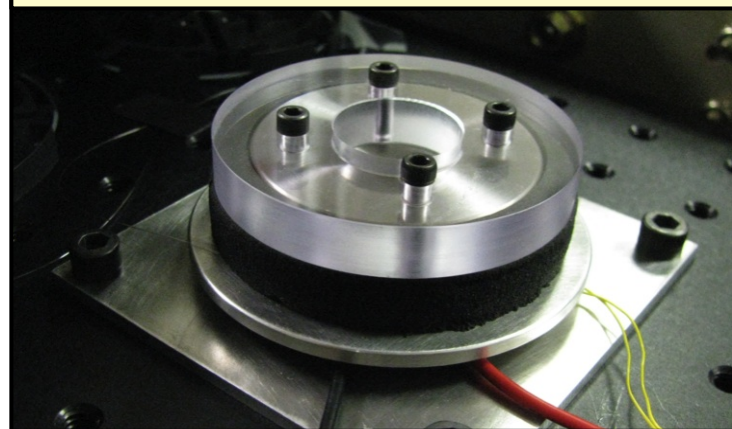
The NIF laser has been configured to increase the 3ω power routinely delivered to the target

- 192 phase plates (CPPs) moved from the 1ω final optics slot upstream of the 1ω vacuum window to the 2ω slot between the frequency conversion crystals
 - Moves the angular divergence of the CPP downstream of the angularly-sensitive Type-I doubler, preserving conversion efficiency at higher power
- 48 AM compensators installed in the NIF front end
 - The frequency modulation applied to the laser pulse in the MOR is converted to amplitude modulation in the preamplifier modules (FM to AM conversion)
 - Spectral pre-filters (AM compensators) tuned for each quad reduce the AM and thus the instantaneous peak power required to achieve a specified power on target

The NIF final optics showing locations for phase plates (CPPs)



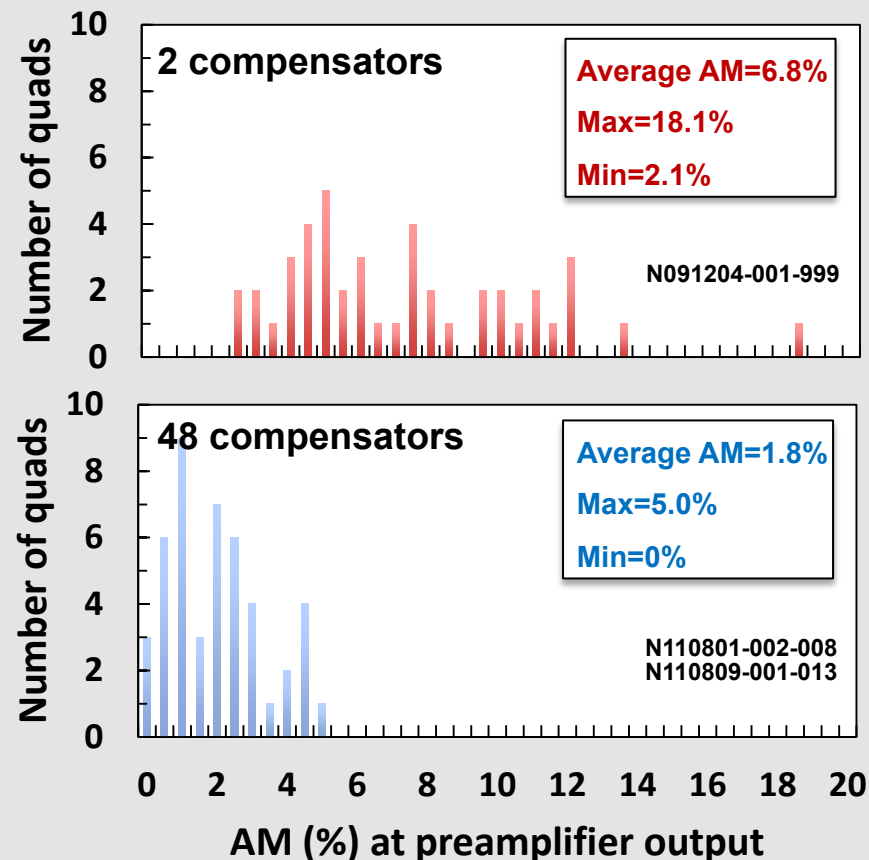
AM compensator uses birefringent temperature-controlled PM fiber



New quad-specific AM compensators reduce AM levels to facilitate high power operation

AM measurements obtained without SSD

$$\delta_m(3\text{GHz})= 5.0, \delta_m(17\text{GHz})= 0$$

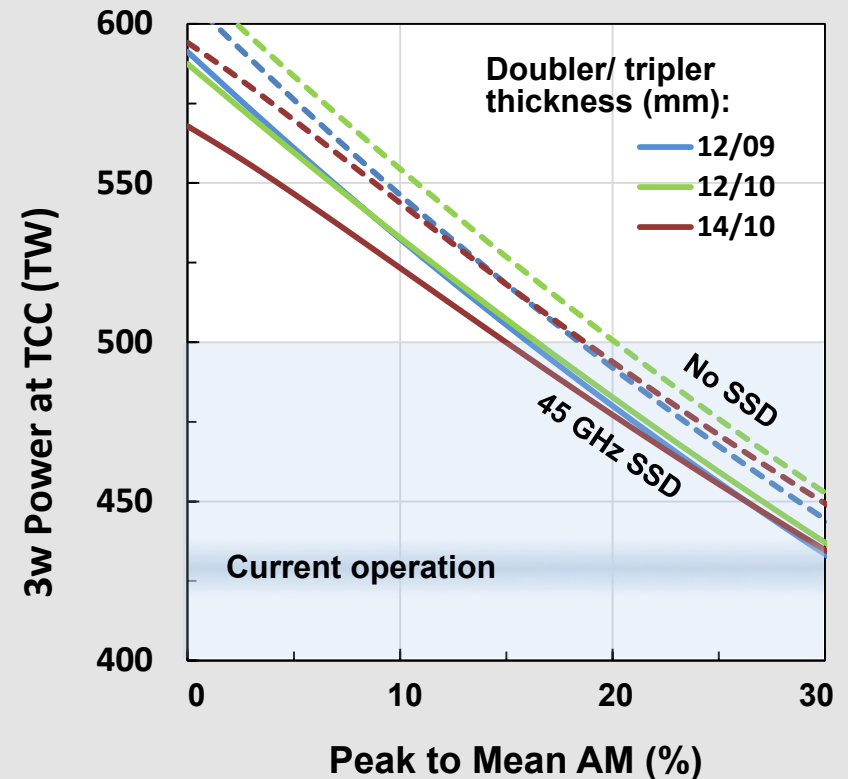


Addition of 45 GHz SSD increases AM by ~3.4x

Simulations show that AM levels need to be held below 10 to 15%

CPP in 2ω slot

90% 3ω transmission, including disposable debris shield



The plan is to fully commission this capability over the next 3 to 6 months